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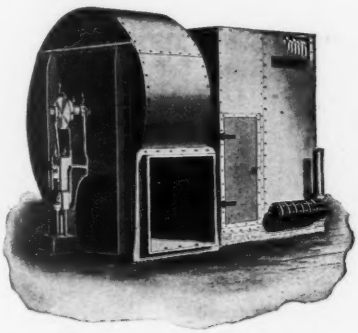

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THE TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

EDITED BY

ROBERT P. BIGELOW, Ph. D.

THE TECHNOLOGY QUARTERLY is an illustrated magazine published by the MASSACHUSETTS INSTITUTE OF TECHNOLOGY. It is devoted to original articles upon various subjects in **Architecture, Civil Engineering, Mechanical Engineering, Electrical Engineering, Physics, Chemistry, Biology, Bacteriology, Mining** and **Metallurgy,** or, in general, the **Sciences** and their applications to the **Useful Arts.** Attention is called to two especially notable features of the QUARTERLY, viz.: *The Results of Tests made in the Engineering Laboratories* and *The Review of American Chemical Research.*

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PROCEEDINGS OF THE SOCIETY OF ARTS.

FORTIETH YEAR, 1901–1902.

BOSTON, October 10, 1901.

THE 555th regular meeting of the SOCIETY OF ARTS was held in the Rogers Building, Room 11, on this day at 8 P.M., President Pritchett presiding. One hundred and ninety persons were present.

The records of the previous meeting were read and approved. The following gentlemen were elected to Associate Membership: Henry A. Morss, Russell Suter, and Frank J. Huse. At the conclusion of the business, Naval Constructor William J. Baxter, U. S. N., was introduced and spoke on "The 'Olympia': a general description of this famous ship, and a discussion of the development of cruisers during the past, and the tendency to future progress."

The "Olympia" was chosen as the standard for comparing the cruisers of the past with those of the future. She was designed nine years ago. The speed developed on her trial trip was unprecedented for a ship of her displacement and class. She has successfully met

every demand which peace and war conditions have placed upon her. In the remodeling which she has lately undergone, it has been neither practicable for financial reasons, nor desirable from strategic reasons, to expend enormous sums of money in making her absolutely "up to date."

The building of the "Olympia" was authorized by Act of Congress, September 7, 1888. The vessel was launched November 5, 1892, and placed in commission February 5, 1895. She was placed out of commission at Boston Navy Yard, November 8, 1899, and will probably be recommissioned during the month of December, 1901. Her value on the morning of the fight at Manila Bay was not far from $3,500,000.

The armored cruisers now building show a great advance in every direction. A comparison of the dimensions, engine-power, speed, coal capacity and armament was made. The present tendency is for the battleship and the cruiser to be combined into a new type which shall unite the speed of the one with the power of the other, limited in size only by the shallowness of our harbors.

Under all ordinary sea conditions every ship must have ample flotation, strength, and stability, and furthermore must be capable of making the greatest speed with the least expenditure of power; with a warship the problem becomes more complicated, as the conditions which may arise in battle must also be considered. In the design of cruisers, the determination of the armament is of the highest importance and governs the outboard design of the whole ship, such as smoke pipes, comfort and beauty. Everything above the water line, outside and inside the ship, must give way to effective use of the guns. Whereas the fashion in guns varies like all other fashions, the shape of the underwater hull once decided upon and built is unalterable, hence the necessity of exercising the greatest care upon a ship's lines.

In this connection the speaker emphasized the value of the experimental tank; for instance, the one in Washington, for studying new and untried models of cruisers and other ships. This was beautifully exemplified in the case of the five latest battleships, whose lines were drawn with the utmost skill and care, based upon previous experience. A few tests in the experimental tank with models gave information which will result in the development of 19 knots with 2,000 less horse power than would have been required with the first

set of lines. After the ship's model has been determined, the necessary strength, water-tightness, safety and stability must be provided for. The inner structure of a steel ship is designed upon the same girder principles as those of bridges, beams, etc., but complicated by the conditions governing safety at sea, and in warships still further by the unusual injuries to which such crafts are liable. For better protection against injury, water-tight compartments are used. The "Olympia" has 145 such compartments.

Referring to sheathing, Mr. Baxter said that it had been shown that an anti-fouling paint successful under one set of conditions is unsuccessful under others; for example, the paint used on trans-atlantic liners with much success is not efficient on vessels cruising in the tropics. Moreover, it seems probable that warships of large tonnage will not be sheathed in the future, as such vessels should be docked at least once a year for the purpose of overhauling and examining the underwater portions of the hull and machinery, no matter whether the vessel be sheathed or not.

The importance of electricity in the modern warship was rapidly sketched. It is used for lighting, for search lights, ammunition hoists, turning turrets, and signaling. There is always a fire alarm system and a telephone system. The very important questions of ventilation and drainage were considered. In closing, the speaker gave a short history of the Boston Navy Yard and its probable position in the near future. "A Navy Yard is more than a shipyard; it is a mammoth workship which contains not only shops and ships, dry docks and all other appurtenances for the repair of all parts of all types of warships, and therefore capable of building ships, it is also a storehouse which distributes all the necessities of a ship, from the ammunition of 12″ guns to the food and clothing of the men who load and fire them. The multiplicity of demands would be tiresome to recapitulate, but it may be well to call attention to a fact not generally recognized in this country, that a Navy Yard, capable of caring for three battleships under emergency conditions, is capable of performing any service of any kind for any merchant vessel and of building any type of vessel."

The thanks of the Society were most heartily extended to Captain Baxter for his able address.

BOSTON, October 24, 1901.

The 556th regular meeting of the SOCIETY OF ARTS was held in the Rogers Building, Room 11, on this day at 8 P.M., Professor George F. Swain presiding. Sixty persons were present.

Professor William Z. Ripley, Expert Agent on Transportation, U. S. Industrial Commission, addressed the Society on "Present Conditions of American Railroads as Compared with the Period of Depression, 1893–1897." The main purpose of the paper was to contrast the present phenomenal prosperity of American Railroads with conditions prevalent during the period of depression, 1893 to 1897, as well as to compare present prosperity with similar periods at an earlier time. The present prosperity, as manifested in an enormous volume of traffic — traffic, moreover, of a higher grade — and finally as resulting in very large net earnings, dividends and surplus, were outlined at length. The great changes in methods of operation, particularly in the train load, were also described. It was shown that more improvement in this respect has characterized the last three years than at any similar period in our history. The paper concluded with a discussion of the bearing of these improvements in operation upon the Interstate Commerce Commission.

BOSTON, November 13, 1901.

The 557th regular meeting of the SOCIETY OF ARTS was held on this day, in the Chemical Lecture Room, Walker Building, at 8 P.M. President Pritchett presided. One hundred and sixty persons were present.

The report of the previous meeting was read and approved. The following persons were elected to Associate Membership: Arthur N. Mansfield, Albert Chittenden, Paul McJunkin. At the conclusion of the business, Professor Arthur A. Noyes was introduced and gave an experimental lecture on "The Importance of Catalytic Agents in Chemical Processes."

Catalysis was defined as the acceleration of chemical reactions by substances which are not consumed in reaction, *i. e.*, they are present at the end of the reaction. The catalytic agents were classified as follows:

1. Carriers.
2. Absorbent contact agents.
3. Electrolytic " "
4. Water.
5. Acids, bases, and salts in solution.
6. Organic colloids, enzymes.
7. Inorganic colloids.

These classes were considered from the experimental and the theoretical standpoint.

Class I. By carriers are meant catalytic agents, which form an indeterminate compound with one of the reacting substances, and thus enable it to react more readily with the other substance.

There is no accepted theory of carrier action. It is known, however, that the rate at which any reaction takes place is proportional to the concentration of each of the substances involved.

Class II. Many solid substances which have the power of absorbing gases cause rapid reaction by mere contact. For example, hydrogen peroxide, H_2O_2, is ordinarily a stable compound, but when mixed with platinum black or bone black there is a quick reaction, the peroxide breaking up into H_2O and O.

$$2H_2O_2 = 2H_2O + O_2.$$

Metals in contact with gases often accelerate any reaction. If a platinum crucible be heated to redness and the flame be extinguished, the platinum crucible continues to glow. The gas is sufficiently concentrated by the platinum to undergo combustion and thus preserve the high temperature. Other experiments illustrating this class of catalytic reactions were given.

There are two theories to explain the action of absorbent contact agents: (1) That the metals really act as carriers; (2) that the substances cause the reactions by increasing the concentration of the reacting gases.

Class III. Electrolytic contact agents. Many metals do not react in solution until another metal is brought in contact with them. This class was illustrated by a number of experiments, one of them being the reaction of tin on hydrochloric acid. On placing the Sn in HCl no reaction followed; on adding a piece of platinum or platinum chloride ($PtCl_6$), however, the tin immediately reacted, forming stan-

nous chloride and hydrogen, the platinum remaining in its original condition.

$$PtSn + 2HCl = SnCl_2 + H_2 + Pt.$$

All reactions of this class may be explained on the electrolytic theory of dissociation. The tin and platinum form a cell, with Sn + and Pt —; the free negative chlorine ions move towards the + Sn, and unite, forming neutral stannous chloride; the hydrogen is attracted to the platinum, where it is absorbed or evolved as gas.

Class IV. Action of water. Many substances when carefully dried either do not react, or else to a very slight extent, whereas the reactions take place readily, often very energetically, when water is present. Among such reactions is that of ammonium chloride, which when dry is not decomposed even at the temperature of 350° C. In the ordinary condition, however, the dissociation takes place readily, ammonia and hydrochloric acid being formed.

$$NH_4Cl = NH_3 + HCl.$$

A very interesting experiment was performed with burning sodium placed in an atmosphere of dry chlorine gas. On introducing the sodium into the tube no reaction took place between the sodium and the chlorine, and consequently the burning sodium was quickly extinguished. On repeating the experiment, using moist chlorine gas, sodium chloride was formed with the evolution of sufficient heat to cause the sodium to glow brilliantly.

There is no satisfactory explanation of the action of water in such reactions, except in the case of solutions. In the latter it is assumed that water causes dissociation of the salt into its ions, and that the reactions take place between these ions.

Many experiments were shown in illustration of Case V, among them the conversion of cane-sugar to glucose and fructose. The laws governing such reactions are: (1) the different acids have different effects at the same concentration on the rate of hydrolysis; (2) the relative effects of different acids on different reactions are the same; (3) the power which acids have of accelerating reactions varies directly as the electrical conductivity.

Owing to the lateness of the hour classes VI and VII were considered very briefly. Experiments were shown illustrating the great importance of unorganized ferments and enzymes in the processes upon which life depends.

BOSTON, November 26, 1901.

The 558th regular meeting of the SOCIETY OF ARTS was held in the Walker Building on this day at 8 P.M., Professor Cross presiding. Three hundred and sixty persons were present.

The report of the previous meeting was read and accepted. The following persons were elected to Associate Membership: Dr. Samuel P. Mulliken and Charles E. Farrington.

Mr. Alex. E. Wurts, Manager of the Nernst Lamp Company, addressed the Society on "The Development of the Nernst Lamp in America." The hall was lighted with Nernst lamps, comparative tests between the Nernst and incandescent lamps were made at the lecture table, and the details of the lamp were exhibited and fully explained.

A full report of the lecture may be found in the "Transactions of the American Institute of Electrical Engineers" for June and July, 1901. A reprint of this paper is on the files of the Society.

An interesting discussion followed, in which Professor Elihu Thomson participated.

The thanks of the Society were most heartily given to Mr. Wurts for his very able and interesting paper.

BOSTON, December 12, 1901.

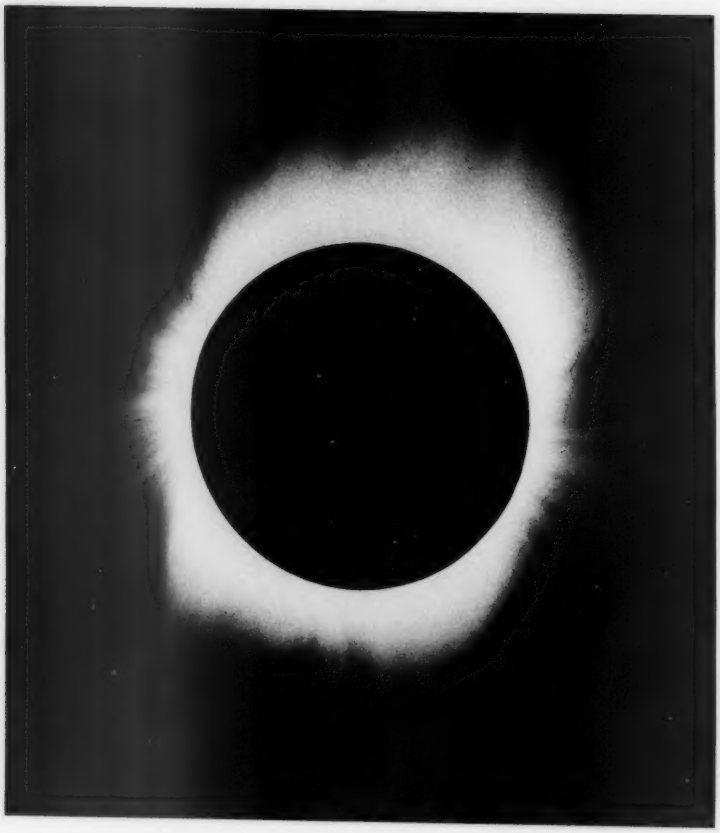
The 559th regular meeting of the SOCIETY OF ARTS was held on this day at the Walker Building, at 8 P.M., President Pritchett presiding. Over four hundred persons were present.

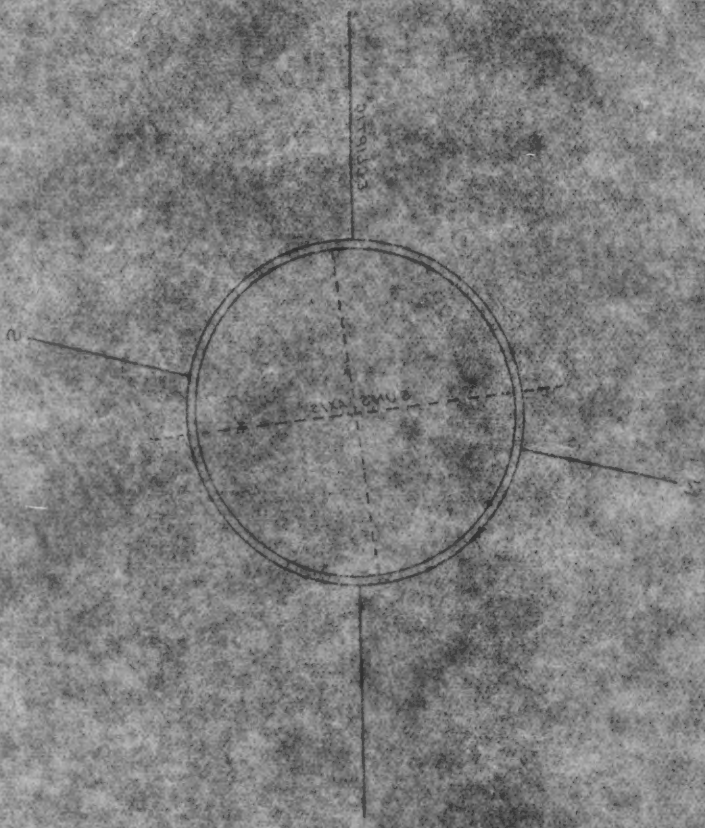
Mr. M. H. Merrill, Westinghouse Elect. & Mfg. Co., Mr. Andrew Raeburn, Westinghouse Church Kerr Co., and Mr. Henry P. James, with Factory Mutual Fire Insurance Co., were elected to Associate Membership.

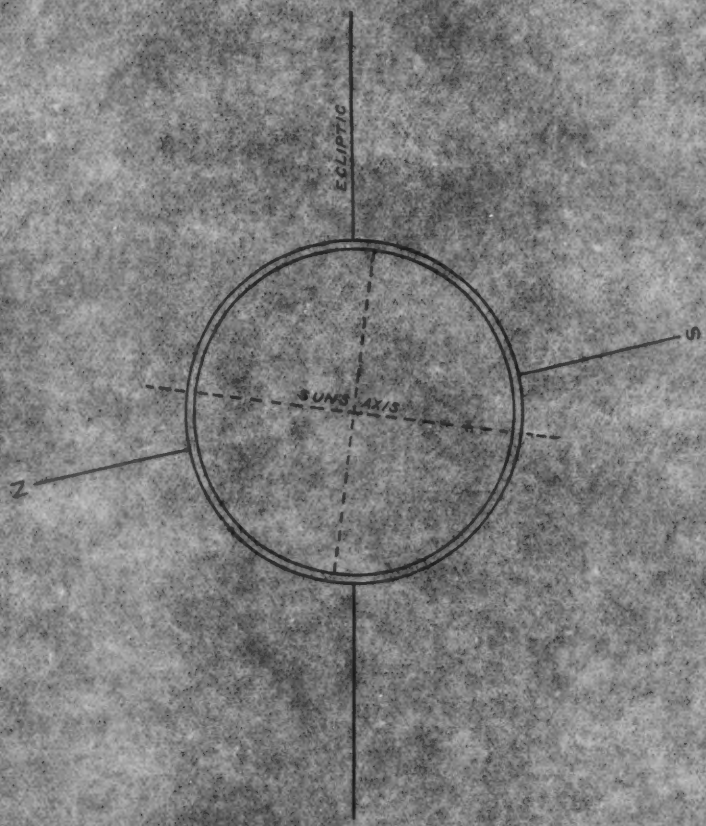
Mr. Cornelius Vanderbilt, of New York, was introduced and gave a very able and comprehensive paper on "The Development of Locomotive Boilers," with particular reference to the "Vanderbilt" boilers. A *résumé* of this paper by Mr. Vanderbilt has been received and placed on file.

The thanks of the Society were most heartily given to the speaker.

GEORGE V. WENDELL, *Secretary.*







HELIOTYPE FROM PHOTOGRAPH OF CORONA, BY HARRISON W. SMITH.

Enlarged to one and one-half diameters. Exposure 20 seconds.

REPORT OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY ECLIPSE EXPEDITION TO SUMATRA IN 1901.

By ALFRED E. BURTON, S.B.

The President, with the approval of the Corporation of the Massachusetts Institute of Technology, decided in January, 1901, to send an expedition to Sumatra to observe a total eclipse of the sun on May 18 of that year, and two thousand dollars were appropriated from the Austin Fund towards defraying the necessary expenses.

The Eclipse of May 18, 1901, was of an exceptional character, the duration of totality being more than six minutes. The track of the shadow extended from Madagascar across the Indian Ocean and through the islands of Malaysia. The west coast of Sumatra furnished the most accessible points of observation. The one unfavorable thing in connection with this eclipse was that the path of totality passed over regions of nearly continuous cloudiness and rain. The weather records of the past years, prepared by the Dutch Committee on the Eclipse, gave some hopeful indications of a clear sky at midday near Padang, in Sumatra, during the month of May.

The writer was placed in charge of the expedition; the other members were Mr. George L. Hosmer, Instructor in the Civil Engineering Department; Mr. Harrison W. Smith, Instructor in the Department of Physics; and Mr. Gerard H. Matthes, Class of '95, Assistant Hydrographer United States Geological Survey; the last-named gentleman is a native Hollander and a graduate of the Civil Engineering Department at the Institute.

As the expenses of the expedition would necessarily be much greater than the appropriation, the writer undertook to secure additional funds from friends of the Institute, and he desires to acknowledge his indebtedness to Mr. John C. Phillips, Mr. Francis Blake, Mr. A. Lawrence Rotch, Mr. Andrew H. Green, and others, whose assistance made the undertaking possible.

President Pritchett decided at the outset that the Institute expedition should try to do some scientific work not directly dependent upon the condition of the weather at the moment of the eclipse, and through the kindness of the Superintendent of the United States Coast and Geodetic Survey, the party was supplied with the half-second pendulum apparatus, which had already been used extensively in this country and in Europe for determining the relative values of the force of gravity at many different points. We were commissioned to swing these pendulums at a new station on the equator

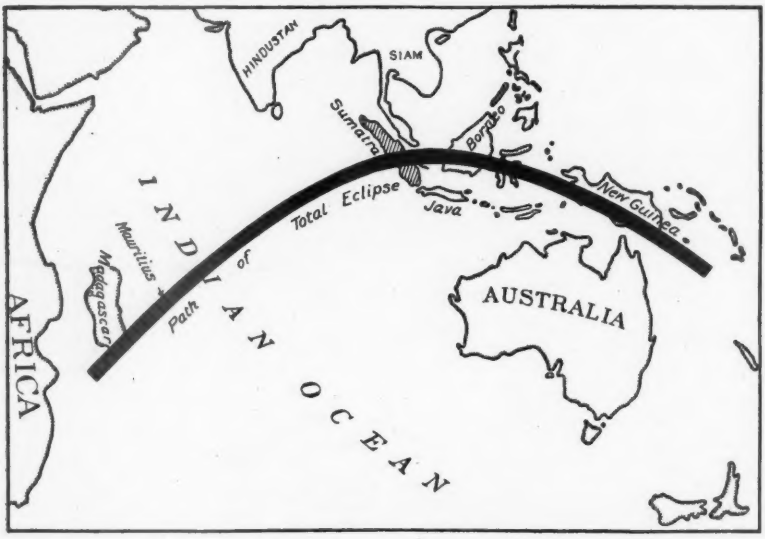


FIG. 1.—PATH OF THE ECLIPSE.

in the Island of Sumatra, thus adding to the data for determining the figure of the earth. We were also asked to swing the pendulums at a station in Singapore which had been previously occupied by a United States government party using another type of pendulum. This last observation was intended to tie together the many results already obtained by these two different types of instruments. It was planned that we should carry on a set of magnetic observations in connection with a general scheme for determining the amount of magnetic disturbance occasioned by the passage of the shadow of the moon over the earth. This work was to be done under the

directions of Dr. Bauer, of the United States Coast and Geodetic Survey, and the instruments to be used were a Kew magnetometer and a Barrow dip circle.

The plan in connection with the eclipse proper included the determination of the times of the four contacts, the photographing of the corona, as well as that portion of the sky immediately surrounding the sun, and the obtaining of direct photographic records of the shadow bands. The outfit used for this part of the work consisted of a 5-inch equatorial telescope, an astronomical transit, a chronograph, and three chronometers for the time observations; three large cameras of 11 feet focal length, and one of 40 inches, with their equatorial mounting, for the photographic work; and six cameras of original design for recording the shadow bands. The astronomical instruments were from the Geodetic Observatory of the Institute; the cameras and shadow band boxes were made at the Institute, under the direction of Mr. Harrison W. Smith; the lenses for the large cameras were ground by Mr. Carl Lundin, of Cambridge, and two of them were generously loaned to us by Professor E. C. Pickering, of the Harvard College Observatory.

It was expected that Mr. A. Lawrence Rotch would join the party at Sumatra with a meteorological outfit, and therefore no instruments of this character were included in our plan.

The route decided upon for reaching Sumatra was the one which presented the least difficulties in the transportation of instruments. The entire equipment weighed about four tons, and included many instruments of delicate construction, which might be easily damaged and thrown out of adjustment by much railroad transportation. Everything was shipped by the Metropolitan Steamship Line from Boston to New York, and then direct to Genoa by steamer "Werra," of the North German Lloyd; there connection was made with the steamer "Koningin Regentes," of the Dutch Mail, sailing to Padang, west coast of Sumatra, with stops for coaling at Port Said and at Perim near the mouth of the Red Sea. This route was not only the safest in the matter of transportation of instruments, but was also the cheapest, as the Dutch Steamship Line gave special rates to astronomical parties and carried our freight free. It proved to be a most comfortable and enjoyable method of traveling, as these Dutch steamers are better equipped for tropical conditions than most of the lines running to the Indies. We also had the

good fortune to meet on the "Koningin Regentes" the members of both the Holland and the two English astronomical expeditions. The Hollanders were Professor A. A. Nijland, Professor W. H. Julius, Mr. J. H. Wilterdink, and Mr. J. B. Hubrecht; the English observers were Mr. and Mrs. H. F. Newall, of Cambridge Observatory; Mr. F. W. Dyson, of the Royal Observatory, Greenwich, and Mr. J. J. Atkinson. This steamer voyage was one of the pleasantest parts of the trip, and from the genial Hollanders we received our introduction to the manners and culinary art of the East Indies. The courtesy of Captain Kotting afforded us the opportunity to charge our storage batteries from the ship's dynamo before reaching Padang.

On April 6 we sailed into Emmahaven, the port of Padang, thus ending the voyage which began in New York on February 24.

We were met at Emmahaven by the United States Consular Agent, Mr. C. G. Veth, who had already arranged for the accommodation of our party. Mr. Veth was most helpful to us during the whole period of our stay. On April 7 we paid our official visit to the Governor of Sumatra. Here we made the acquaintance of Major J. J. A. Müller, in charge of the survey of the island, and Mr. R. Delprat, Director and Engineer of the State Railroads. Everything possible in the way of courtesy and hospitality was shown to us by these gentlemen. After consultation with Mr. Delprat, the writer decided to visit the coal mines at Sawah Loento in search of a site for an observing station. On April 8, armed with a letter of introduction to Mr. van Lessen, Chief Engineer of the Mines, Mr. Matthes and the writer journeyed a hundred miles into the interior. At Sawah Loento we found a neat little hotel, newly erected for the accommodation of visitors to the mines, and south of the hotel, and not much more than a mile away, we found a favorable spot for the erecting of piers and houses for instruments. Labor and material for building appeared in abundance, and with Mr. Matthes for interpreter, we soon came to a satisfactory and definite settlement. Two days later we moved our entire outfit by rail to Sawah Loento; transportation for both passengers and freight was furnished free. Through the kindness of the "Comptrolleur," Mr. Sieburgh, bands of convict laborers were assigned to us, roads were extended to our station and a site for the building was cleared and leveled. Brick and cement for the piers and bamboo for the houses had to be

carried up by water-buffalo carts and coolie laborers. Six thousand bricks and thirteen barrels of cement were required for the piers alone. It is not wise, or even possible, to rush work under the equator, and it was not until April 17 that the masonry work began. Our best workmen, both in brick laying and in house building, were hired Chinamen, the native Malay not taking kindly to this sort of labor.

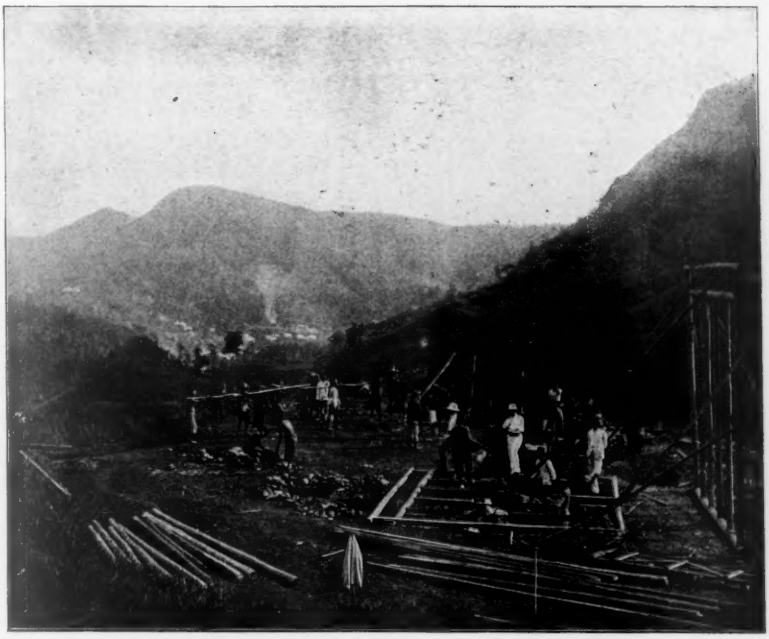


FIG. 2 — WORK AT M. I. T. STATION, APRIL 17TH.

On account of the excessive rain it was necessary to build the houses before any of the instruments could be transported to the station. The camera house was completed April 22; the transit and pendulum house on April 28; the instruments were brought to the station from the Sawah Loento depot on April 29. During the first week in May, Mr. Smith's camera frame was placed in position, the focal length of the lenses determined, the cameras attached to the frame, and the polar axis adjusted in position on the tops of the piers.

Mr. Hosmer completed a set of pendulum observations on May 8, a full account of which will be found in his appended report.

As it was desirable that the magnetic observations should be made at a point free from any accidental local attraction, it was decided to build a special magnetometer hut on an adjacent mountain. This magnetometer shelter was built by the native Malays of bamboo and thatched with grass, no nails or metal of any kind being used in its construction. The hut could only be reached by a difficult climb,

FIG. 3.—GENERAL VIEW OF THE STATION ON THE DAY BEFORE THE ECLIPSE.

and there was absolutely no danger of the work being disturbed by passers-by. Mr. Hosmer made the observations with the magnetometer, and a full account of these will be found in his report.

The Eclipse Station of the English Astronomical Party, in charge of Mr. H. F. Newall, of Cambridge, was established at a point about a mile northwest of the mines and three miles north of our station. We were able to see from one station to another, and time signals were sent to Mr. Newall from our station on several days previous to the eclipse. Dr. S. A. Mitchell, of the Naval Observatory, located

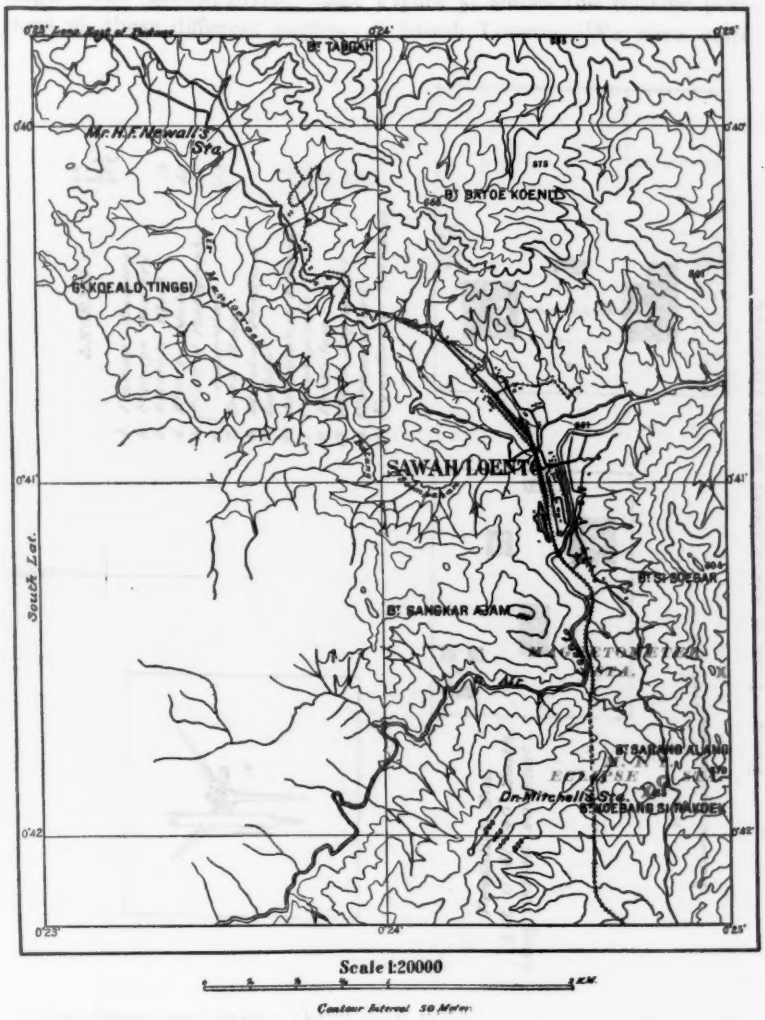


FIG. 5.—MAP SHOWING LOCATION OF ECLIPSE STATIONS NEAR SAWAH LOENTO.

M. I. T. Eclipse Station marked by red circle; the Magnetometer Stations, by red crosses.

FIG. 5.—MAP SHOWING LOCATION OF ECLIPSE STATIONS NEAR SAWAI LOENTO.

M. L. T. Eclipse Station marked by red circle; the Magnetometer Station, by red square.

his instruments a short distance to the west of us and on the same ridge. The accompanying map, Figure 5, shows the relative positions of these different parties at Sawah Loento. We were quite

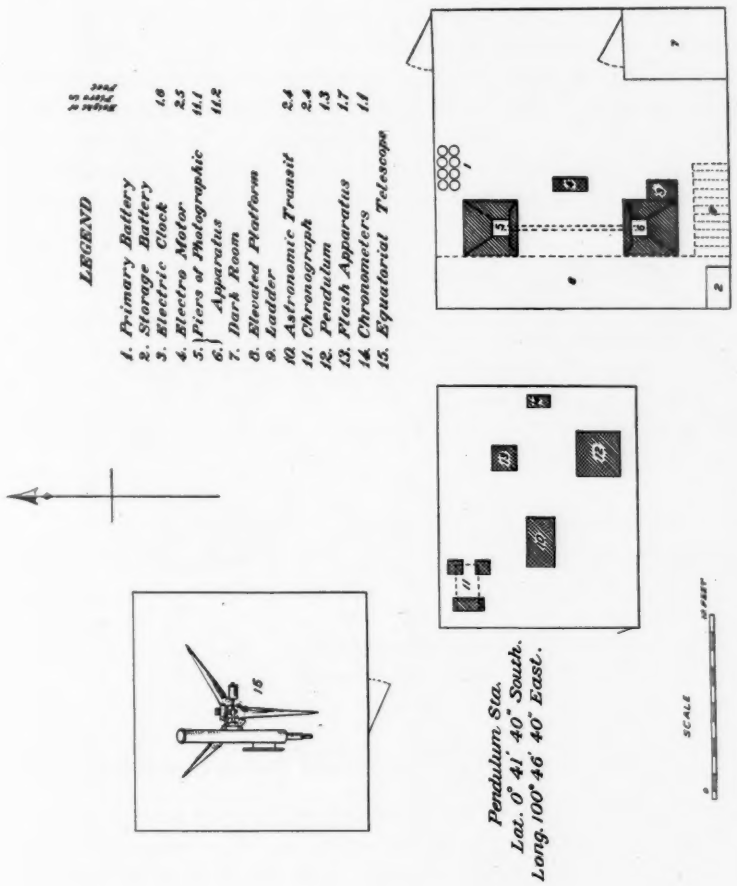


FIG. 4. — PLAN OF ARRANGEMENT OF THE APPARATUS.
Altitude of pendulum station, 1246 feet.

near neighbors, and during the month of preparation were able to be of some mutual assistance.

Not until the evening before the eclipse was everything in readiness for the work in hand; there had, fortunately, been enough clear days and nights for the necessary adjustments.

The hill on which our station was situated was called in the Malay language "Boekit Koebang Sirakoek."

Noon was the hour of totality. During our days of preparation we had noted but few times when the weather was favorable at this hour. The morning of the 18th of May was very hazy, with low clouds hanging over the mountains and drifting through the valleys. At ten o'clock the sky cleared, and at the time of the first contact was everything that could be desired. Soon after, light patches of cloud

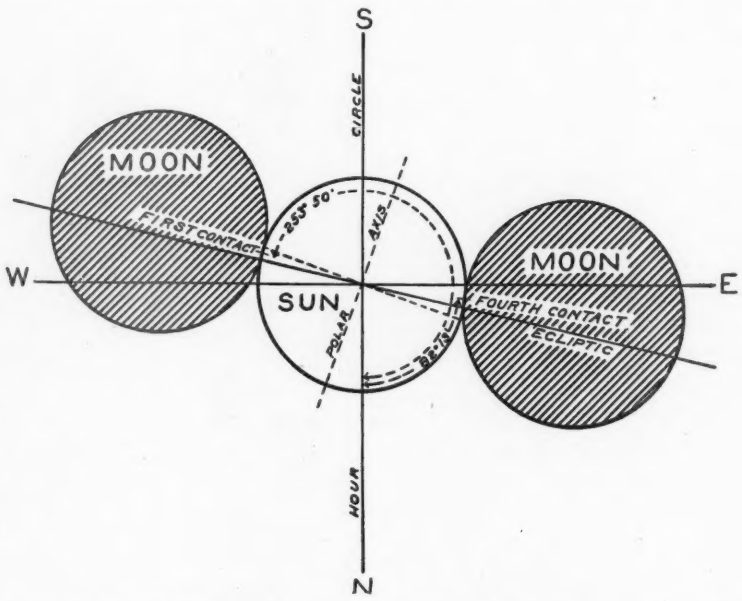


FIG. 6. — DIAGRAM SHOWING POSITIONS OF POINTS OF FIRST AND FOURTH CONTACTS.

began to blow across from the northeast, but the sun was never very much obscured. During the whole period of totality the corona was plainly visible to the naked eye, and at moments was very clearly defined. This was not the case at other points close at hand; at our magnetometer shed, which was only half a mile distant, the clouds were so thick that even the times of the second and third contacts could not be noted, and just before totality a colored halo was seen about the sun.

Mr. Smith carried out the prearranged plan for the exposure of

the photographic plates without mishap or accident. After developing the plates, he found that he had an excellent negative of half-second exposure near the moment of the second contact, showing the prominences, and a very clear negative of twenty seconds' exposure, showing the corona. Half-tone and heliotype reproductions from enlargements of these plates are presented with this report. A detailed account of the photographic work is also given by Mr. Smith. The photographic reproductions fail to do justice to the sharpness and clearness of detail in the original negatives.

Observations for the times of the four contacts were made by the writer. The sky was sufficiently clear at these moments to make it possible to obtain exact records.

Time Observations.

Using the latitude and longitude of our station as given on the topographical map of Sumatra, and assuming that the longitude of Padang was 100° 20′ 32″ † east of Greenwich, we computed the times of the four contacts from the elements given in the American Nautical Almanac. The longitude of Padang has been obtained simply by transfer of chronometers, and is therefore not to be entirely depended upon.

The observations were made with an equatorial telescope, with 5-inch objective, and were recorded on a chronograph by means of an electric key, held in the hand of the observer.

TABLE OF PREDICTIONS AND OBSERVATIONS.

Greenwich Mean Time.

May 17, 1901.

	Position Angle.	Prediction, G. M. T.			Observed.		
		h.	*m.*	*s.*	*h.*	*m.*	*s.*
First contact	253° 50′	16	05	19.6	16	05	01.2*
Second contact . . .		17	39	16.4	17	38	59.1
Third contact . . .		17	44	58.1	17	44	47.0
Fourth contact . . .	82° 13′	19	17	21.4	19	16	59.7

† The longitude of Padang here given is from the American Ephemeris and Nautical Almanac for 1901. We understand that Major Müller gives the longitude as 100° 21′ 55″ E. This value will reduce the differences between observed and predicted times of contact.

* See foot-note on page 18.

Local Mean Time.

May 18, 1901.

Number of Contact.	Predicted.				Observed.				Difference.
		h.	*m.*	*s.*		*h.*	*m.*	*s.*	*s.*
I	A.M.	10	48	26.3	A.M.	10	48	07.9*	— 18.4
II	P.M.	12	22	23.1	P.M.	12	22	05.8	— 17.3
III	P.M.	12	28	04.8	P.M.	12	27	53.7	— 11.1
IV	P.M.	2	00	28.1	P.M.	2	00	06.4	— 21.7

Predicted length totality, 5*m*. 41.7*s*. Observed length totality, 5*m*. 47.9*s*.

The second and third contacts were both observed with an open eyepiece, without the shaded glass, and the writer feels sure that the observed period of totality cannot be in error by more than one second.

The fourth contact was observed with a clear sky, and is the most precise of the series.

Mr. Matthes took charge of the shadow band work, and his written report is here given:

REPORT ON THE OBSERVATION OF SHADOW BANDS.

By GERARD H. MATTHES, S.B.

In order to observe the shadow bands, a large white sheet was stretched out in the centre of the area occupied by the shadow band cameras. Two laths, each 10 feet long, made of split bamboo, were used to indicate the direction of movement of the lines. The six shadow band cameras were arranged in two rows of three each, running east and west. The boxes[1] were placed with their main axes as follows, the directions given being those in which their respective shutters moved:

First row, exposed before second contact:
No. 1, E. to W.
No. 2, S. to N.
No. 5, S. E. to N. W.

Second row, exposed after third contact:
No. 3, S. W. to N. E.
No. 4, S. to N.
No. 6, E. to W.

In order to prevent shifting during the instant of exposure, the cameras were held in place by small piles of brick disposed around them.

* The exact moment of first contact was missed, but a record was made on the chronograph and the angular length of the arc of contact estimated; when the arc of contact just before the fourth contact appeared of the same length, another record was made on the chronograph, and the interval of time between this last record and the fourth contact was then applied as a correction to the first observation.

[1] The construction of the shadow band boxes is described in Mr. Smith's Report on Photographic Work.

The operation of exposure consisted, first, of uncovering the camera; second, of pulling the string liberating the shutter; third, of covering up the camera.

The cardboard covers, with which each camera was provided, were removed about five minutes prior to the advent of the bands and replaced immediately after exposure. The exposures were made at a signal given by me to Messrs. W. van der Valk, C. van Overeen, and A. van Eugen, who courteously had offered their services for this purpose.

A few seconds before the second contact, dim shadow bands became visible, extending in a north-south direction, and moving from east to west. Owing, probably, to the cloudiness at that instant, the bands were indistinct, and their duration, it is estimated, did not exceed five seconds. The cameras in the first row were exposed in succession, their order being No. 1, No. 5, and No. 2. Cameras No. 1 and No. 5 were duly exposed, but by the time the shutter of No. 2 moved, the bands had already disappeared.

Immediately after the third contact the shadow bands became again visible.

The bands were well defined, and upon their appearance I gave the signal for the three remaining cameras to be exposed simultaneously. The bands at this time remained visible for about twenty seconds, increasing for a while in intensity, then fading gradually as the sunlight became brighter.

I had opportunity to verify the direction of the lines, and found it to agree exactly with that obtained at the previous observation.

Of the cameras, it was found that No. 4 failed to work properly, and that the shutter of No. 6 did not quite close.

As a summary of the eye observations, made at both times, the following statement may be made:

The bands appeared to be one-half inch wide, very sinuous and from two to three inches apart, their general appearance bearing a striking analogy to the ripple marks on a sandy beach.

Their motion was both vibratory and translatory, *i. e.*, the sinuosities were seen to undulate rapidly, while at the same time the band as a whole progressed from west to east. The fact that the bands were in constant vibration, together with the apparent merging of bands into each other, made it exceedingly difficult to gain an idea of their velocity of translation. It was further observed that the bands would disappear, new bands appearing in their places with great frequency. In short, while the character of the bands themselves was easily observed, also that the bands moved from west to east, *i. e.*, at right angles to their general direction, the determination of their velocity seemed well-nigh impossible.

From the above it is evident that to measure the velocity of any one band in particular would be attended with considerable difficulty, owing to the uncertain nature of its movements. Nor would such a determination, if made, be at all representative of the movement of the shadow bands as a whole. Obviously, the latter velocity is the only one of consequence. As to its value, I find it impossible, however, to make an estimate that would rest on any degree of conviction.

In addition to making these observations, Mr. Matthes made a plan, showing the location of the different instruments, traced from the government topographical survey the accompanying map of Sawah Loento and the surrounding country, and it was through his services as interpreter that we were enabled to keep in intelligent communication with our official friends, and to profit by their kindness and assistance.

On the evening of May 18th we received telegraphic reports of the results obtained by the different astronomical parties. There was

a general tone of disappointment. It was from the station of Fort de Kock alone that we received news of a perfectly clear sky. A few days after, a more hopeful view of the situation was taken by several of the parties; the developed plates revealing more than was anticipated.

There were gathered together on the west coast of Sumatra, in the northern half of the shadow's track, some eleven different eclipse expeditions. The accompanying map will indicate the positions occupied by these parties. The Holland Party was located near Painan, on the coast, almost exactly on the central line of the eclipse; near them, on the Island of Aoer Gadang, was the English party from the Greenwich Observatory; at Padang were the Lick Observatory Party, the French and Russian Observers, and several Jesuit Fathers from the Calcutta and Manila Observatories; on the coast near Padang were located the instruments of the Japanese astronomers; at Solok, on the railroad line to the coal mines, was gathered the larger part of the Naval Observatory Expedition; at Sawah Loento there were Mr. H. F. Newall and his English party, Dr. S. A. Mitchell, from the Naval Observatory, and the party from the Massachusetts Institute of Technology; at Fort de Kock, near the northern limit of the shadow's track, observations were made by Dr. W. S. Eichelberger, Dr. Humphreys, and Mr. Peters, of the Naval Observatory Party.

On the day of the eclipse all weather predictions seemed to fail; those places where the indications had been most favorable were then visited with the cloudiest skies; and some spots considered entirely unfit for occupation furnished exceptionally fine weather at the critical moment. Solok was one of the most unfortunate locations, and Fort de Kock the best. Fort de Kock was very near the northern margin of the shadow, but at Padang Panjang, well within the track, where no one had dared risk a location, the conditions were ideal.

After the photographic plates had been developed there was no farther work at Sawah Loento; only to pack our goods and to thank the officials and people in this community for the kind assistance and courtesies extended to us. To Mr. van Lesson, chief engineer of the mines, to the comptrolleur, Mr. Sieburgh, and to Mr. van der Valk, we are much indebted for special help in the construction of our buildings and masonry. All of our outfit which was not needed for the pendulum observations at Singapore was sent directly back to New York by steamer.

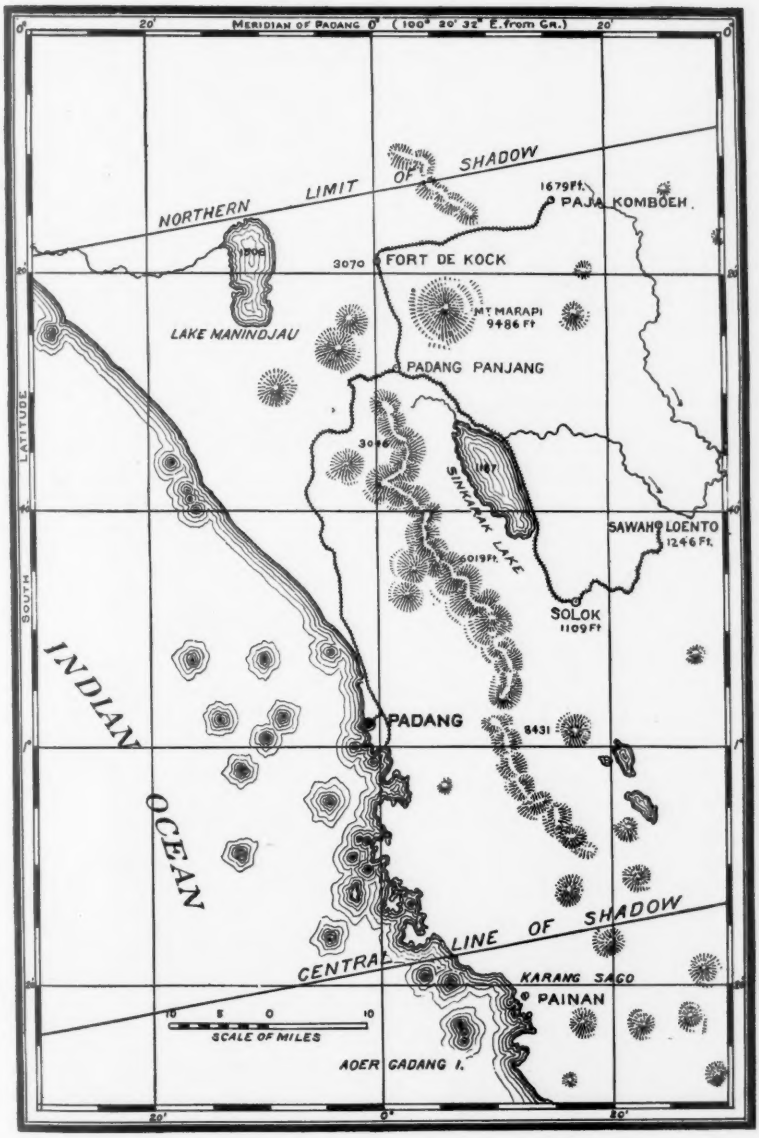


FIG. 7. — MAP SHOWING LOCATIONS OF ALL THE ECLIPSE EXPEDITIONS TO THE WEST COAST OF SUMATRA.

A collection of costumes, household utensils, and weapons, to illustrate the life and manners of the native Malays of Sumatra, was made by the writer, with the valuable assistance of Mr. Schilds, of Padang, for the Peabody Museum at Salem, Massachusetts, and is now on exhibition there.

On May 24th the party took passage on the "Koning Wilhelm II" for Batavia; here we made a close connection with the steamer "Van Riemsdijk," of the Royal Dutch Packet Line running to Singapore. From this port Mr. Smith and Mr. Matthes took the next connecting steamer to Japan, while Mr. Hosmer and the writer remained at Singapore to make the pendulum observations. Two stations were occupied on the ground floor of the European Hospital, one of these being at the exact spot used by the United States Government Party twenty years ago. We are grateful for assistance from the office of the Colonial Engineers, and we are especially indebted to Mr. R. Symonds Fry, in charge of the Time Service at Singapore, for the opportunity of using his transit in making the time observations. A record of the pendulum work is given in full in Mr. Hosmer's appended report.

All the remaining instruments of our equipment, with the exception of the three chronometers, were now packed and sent by steamer back to New York. Mr. Hosmer and the writer took the steamer "Bayern," of the German Mail, for Yokohama, Japan, stopping on the way at Hong Kong, Shanghai, Nagasaki, and Kobe. After fourteen days' sight-seeing in Japan, we embarked on the "America Maru," of the "Toyo Kisen Kaisha," Line, stayed half a day at Honolulu, and arrived at San Francisco August 1st. In a few more days we were back in Boston. Liberal reductions in rates had been given to the party on all steamer lines and railroads, and the greatest interest shown in our work by the officials whom we met.

Report of Photographic Work.

By HARRISON W. SMITH, A.B., S.B.

The photographic outfit included three lenses of 3-inch aperture and 135-inch focus, two of which were loaned by Professor E. C. Pickering. There was also a 3-inch lense of 40-inch focus, which, though not adjusted for photographic work, had been successfully used in Georgia in May, 1900, in photographing the faint elongations of the equatorial streamers. This lense was designed for use

both with ordinary plates and with isochromatic plates and a color screen. Of the first mentioned lenses, one was to be used for the corona, while two were for photographing regions of the sky east and west of the sun, in the search for intra-mercurial planets.

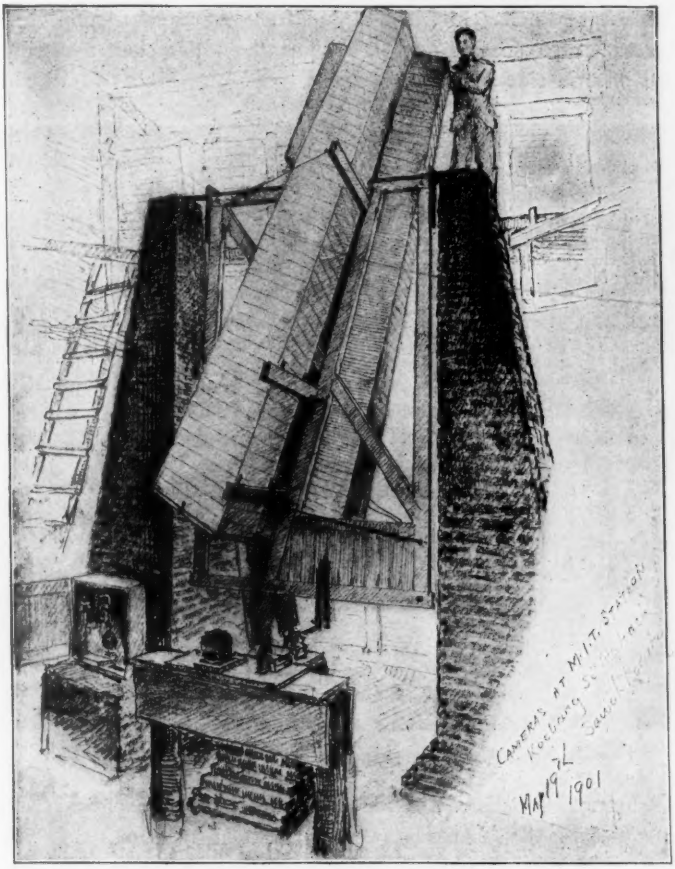


FIG. 8. — SKETCH SHOWING METHOD OF MOUNTING CAMERAS.

The cameras were long square boxes of pine sheathing, and were taken apart before leaving Boston and shipped in crates, this method of construction being found very light and especially satisfactory on account of the rigidity of the cameras after being mounted. All four

cameras were fastened to one framework, 6 feet wide by 8 feet high, which hung from a polar axis supported on brick piers, 11 feet in height. The fact that our station was only a few miles from the equator, and that the eclipse occurred a short time after noon, made this method of mounting very convenient. The polar axis was a steel shaft $1\frac{1}{4}$ inches in diameter, and the frame was supported by two brass straps passing over it. Thus the whole cluster of cameras — two on one side of the axis and two on the other — formed one

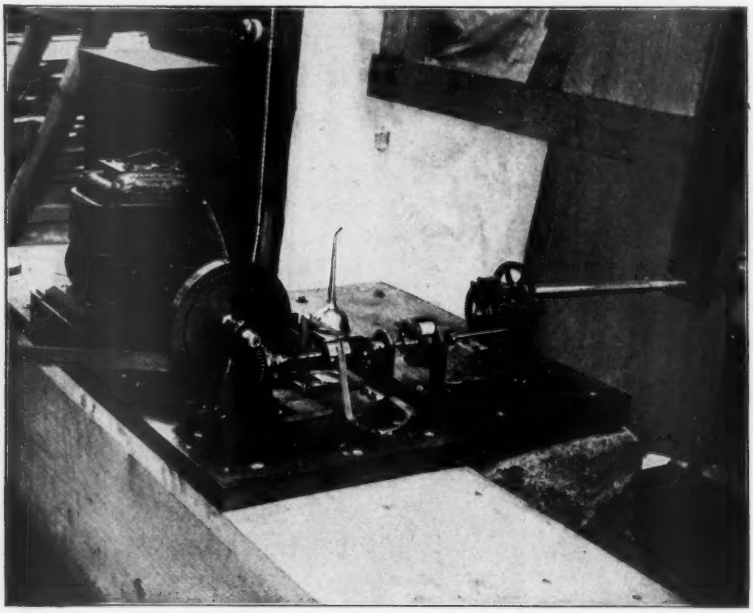


FIG. 9. — CONTROLLED MOTOR AND TANGENT SCREW.

rigid structure, so balanced as to swing freely through the necessary angle. Before the cameras were placed in position, they were focused on a dark window in a blue house at a distance of about two miles. A base line was measured and the distance determined by triangulation; the focus was then corrected for parallel rays, and finally the cameras were placed in position and the focus tested by obtaining trails from Arcturus, whose declination is very nearly the same as was that of the sun at the time of the eclipse. The trails showed that the focus was practically correct.

The driving of the cameras was accomplished by means of an electric motor, acting through a train of gear wheels on a tangent-screw. One end of the screw passed through a nut fixed at the end of the frame at a distance of 102 inches from the centre of the polar axis, while the other end was suitably supported on a brick pier. Figure 9 shows the arrangement of the motor, gearing, and tangent-screw before the cameras were placed in position. The motor was maintained at the proper speed by means of an exceedingly ingenious method of clock control, devised at the Harvard College Observatory by Professor E. C. Pickering and Mr. William P. Gerrish, which may be described as follows: A flexible coupling connects the motor to a comparatively heavy fly-wheel, which, in turn, is joined by a worm and gear to a shaft so designed that it will make exactly one revolution per second when the tangent-screw is being driven at the desired speed. This shaft, which may be seen at right angles to the motor shaft, is provided with a make-and-break contact (about halfway between the bearings), so arranged that a brush resting on a disk, composed half of brass and half of vulcanite, closes a circuit during one half of a revolution and opens it during the other half. Figure 10 is a diagram of the apparatus and the electrical connections, showing at K this contact disk, at M the motor, at R a relay, and at P the pendulum of the controlling clock, which beats half seconds. Attached to the end of the pendulum rod is a strip of platinum that, during each swing of the pendulum to the left of its middle position, cuts through a meniscus of mercury, thus alternately opening and closing a relay circuit at intervals of one half second. In the figure the meniscus of mercury is shown for clearness slightly below the platinum tip. This relay contact and the contact K are electrically connected in series with each other and with the motor, and are then joined to a storage battery of a size sufficient to furnish considerably more power than necessary to drive the motor at its proper speed.

Thus the motor is driven by a series of impulses, succeeding each other at intervals of one second, for the motor can only receive current when both the relay and the contact at K are closed. The figure represents the condition of things when the pendulum is just on the point of closing the circuit while the brush of the contact disk is on the point B; so that current will flow until the disk, revolving in the direction represented by the arrow, has brought the

point *D* under the brush, and the circuit is broken. If the acceleration represented by the arc *BD* is sufficient to maintain the proper average speed, the point *B* will again be under the brush when the clock closes the circuit one second later; if, however, this acceleration is insufficient, the motor will drop behind a little, and when the circuit is closed the point *A*, for example, will be under the brush, so that the acceleration will continue for a greater interval, represented by the arc *AD*. If, on the other hand, the acceleration were too great, the point *C* would have arrived under the brush when the circuit was closed,

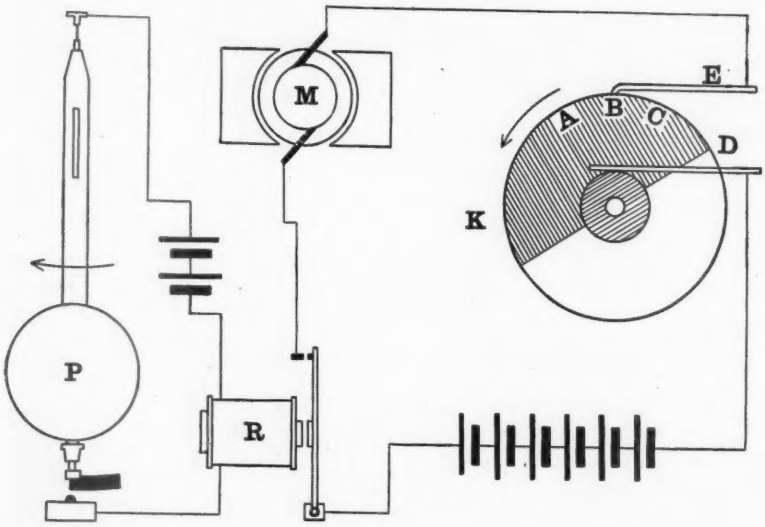


FIG. 10. — ELECTRICAL CONNECTION OF THE CONTROLLED MOTOR.

and the acceleration would continue during the interval *CD* only. The device constitutes a form of electrical cut-off, in which the clock closes the motor circuit, while the motor opens the circuit, after taking the amount of energy it requires, thus maintaining the average speed absolutely constant. The speed, of course, rises and falls each second, but these fluctuations may be reduced to any desired amount by increasing the weight of the fly-wheel and by a slight modification of the electrical connections. Let the motor be connected permanently to the battery, but with a resistance, inserted in series with the armature, of such magnitude as to reduce the speed of the motor

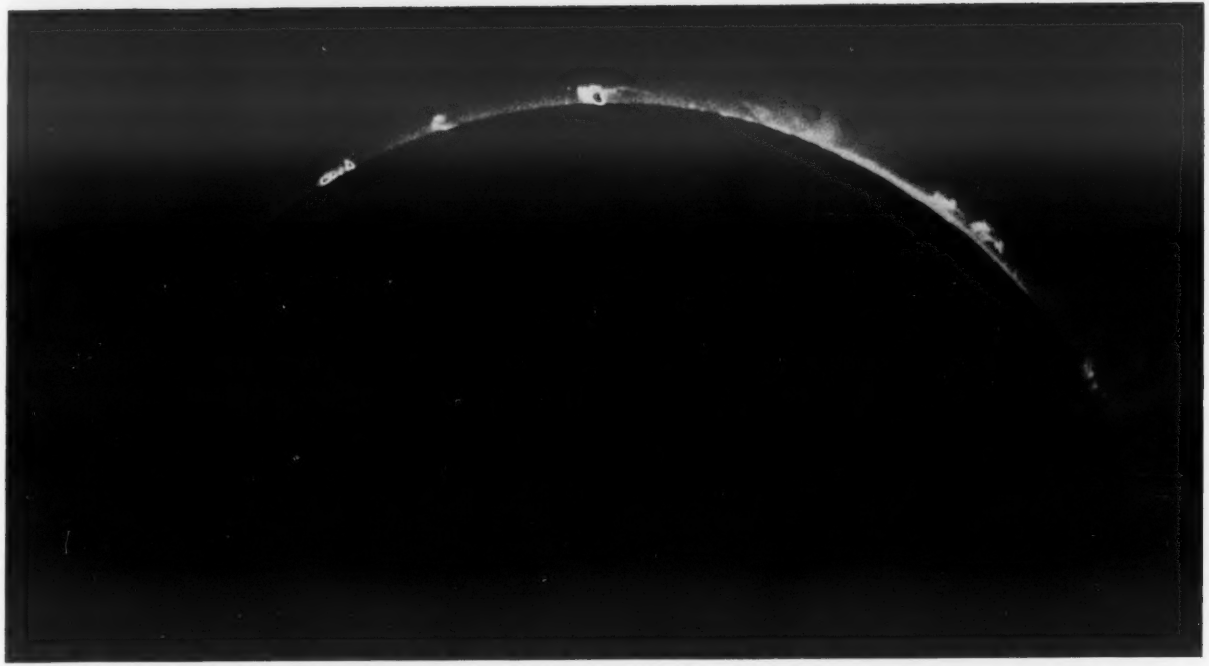


FIG. 11. — HALF-TONE REPRODUCTION FROM PHOTOGRAPH OF PROMINENCES AT TIME OF SECOND CONTACT. Enlarged to 5 diameters.

somewhat below its normal rate ; the control device may then be used to short-circuit this resistance, thus producing a small acceleration each second and gaining the desired regulation with very small fluctuations in speed. A portable storage battery of six 5-ampere cells was found sufficient to drive the motor.

Through the courtesy of the ship's officers, the battery was charged on the steamer just before reaching Padang, and was maintained in perfect condition by means of a bichromate battery. This method of driving the cameras was found most satisfactory by the writer and gave no trouble whatever. The clicks of the relay and the hum of the motor, during the short intervals in each second when it is receiving current, produce a rhythmical sound, by which one very soon learns to judge accurately whether or not the motor is "in step" with the clock. For this reason, the method possesses a distinct advantage over many of the other forms of driving devices, in that, having once completed the adjustment, there is no possibility (aside from an exceedingly improbable change in the rate of the clock) that the apparatus will fail to work correctly without the operator becoming instantly aware of the fact.

Of the three cameras of 135-inch focus, the two used for photographing the sky near the sun were designed to take two 8 × 10 plates, each slightly tilted to improve the focus. As it was intended to give a very long exposure with these cameras, it was necessary to cut down the number of exposures for the other camera, which was intended to photograph the corona, it being considered unwise to attempt any manipulation on one camera while the others were exposing. Unfortunately, the long exposure was of no advantage, since the cloud was so dense on each side of the sun that scarcely any stars are to be found on the plates. Of the exposures with the third camera, the first, of one-half second for the prominences at second contact, and the last, of twenty seconds, were successful. The other negatives were badly fogged by the diffused light from the clouds, and are of no value. The two referred to are, however, good, clear negatives. The prominences, although not large, are interesting, and there is evidence of a very violent disturbance in the equatorial region on the easterly limb of the sun. This disturbance is also plainly visible on the negative of twenty seconds' exposure, and is accompanied by a marked crossing of the filaments, radiating from a point having a position angle of 60° to a distance of eight or nine minutes

of arc from the moon's limb. A particularly striking dark arch appears on the easterly limb over a prominence of which the position angle is 115°. The polar streamers extend nearly one-half diameter from the moon's limb and the equatorial streamers on the west fully one diameter. This negative was undoubtedly exposed at an opportune moment, when a slight opening in the clouds was passing over the sun, for it shows very little indication of fog. The negatives from the 40-inch camera are all fogged, and the writer scarcely hoped for anything better, since the appearance of the sky near the end of totality was very discouraging, a bright halo of light surrounding the sun on all sides. The more striking features of the corona and prominences are shown in the accompanying diagram, Figure 12.

A very weak Ortol developer was used, in which the plates were soaked from one and one half to two hours. Fortunately, ice was easily obtainable from Padang, for otherwise it would have been impossible to prolong the development to such an extent; in fact, it would have been difficult to accomplish anything, since the temperature of the water in the dark room was never below 80.5° F. The Seed double-coated plate was used for the corona, as it was found to have yielded excellent results at the eclipse of 1900. No more difficulty was experienced in manipulating these plates than the ordinary plates, and the writer is firmly convinced that the negative contains detail in the inner corona, which can be reproduced by careful shading of the negative during printing, that would have been lost by over-exposure in an ordinary single-coated plate. It is a pleasure to acknowledge the kindness of Mr. W. van der Valk in offering the use of a dark-room with excellent water.

For the purpose of keeping time, a special clock was arranged with the escapement wheel on the minute shaft, so that the minute hand read seconds and the hour hand minutes. The clock was started at the second contact at twelve, and the bell struck minutes and half minutes, thus indicating the lapse of the period of totality. Mr. A. M. D. van Kuylenburg attended to starting the clock and to giving signals. The writer is especially indebted to Mr. Ch. Logeman, engineer at the mines, for invaluable and skillful assistance in exposing the cameras.

In addition to the work already described, an attempt was made to photograph the shadow-bands by a method which, so far as the writer knows, has not previously been tried. Although the results

were not satisfactory, they were such as to make it appear that the method is worth another trial, especially since the bands were not sufficiently distinct to give the method a thorough test. In brief, it consists merely in exposing a sensitive plate directly to the bands themselves, rather than attempting, with a camera, to photograph them as they appear on a white screen. The exposing is done by means of a sort of large focal plane shutter. Three 8 × 10 plates

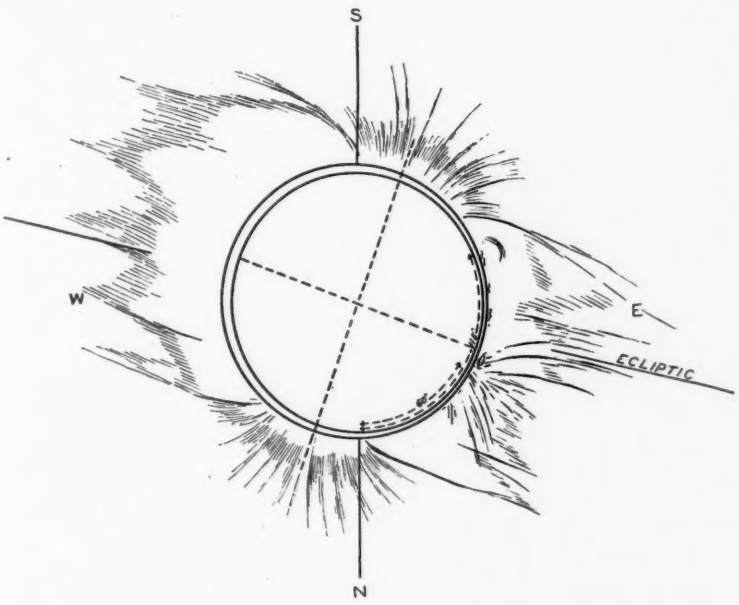


FIG. 12. — DIAGRAM SHOWING ANGULAR POSITIONS OF DISTURBANCES ON THE EASTERN LIMB OF THE SUN.

were placed in the bottom of a shallow box, giving an area 10 × 24 inches. Over this was a light-tight screen of two pieces of rubber gossamer, cemented together on the rubber side. The screen is attached at each end to a curtain roller, a narrow slot is cut across it at the proper point, and the operation of exposing consists in rapidly drawing this slot over the sensitive plate by means of rolling the screen up on one roller while it is being drawn off from the other. The boxes, for several were used, were laid flat on the ground, and were exposed under the direction of Mr. Matthes, who was familiar

with the appearance of the bands. The diffused light, however, was so great that it was hardly to be expected that the bands would appear upon the plates. In fact, the plates indicate over-exposure. As the exposures averaged about $\frac{1}{100}$ second, it is probable that $\frac{1}{200}$ to $\frac{1}{500}$ second, or, perhaps, $\frac{1}{1000}$ second, would be sufficient for plates of moderate speed. Plates of different speed were used, but as they all show over-exposure, it would probably be advisable in another attempt to err on the side of too short rather than too long exposure. It would be better, also, to substitute for the cloth a metallic screen that could be moved at a more uniform rate. It was found that a cloth screen, 12 inches or more wide, with a slot across nearly its entire width, did not run as smoothly as could be wished, while a metallic screen could be made to slide freely and would not be affected by having a slot of any width cut across it.

The apparatus was tested successfully on artificial shadow-bands before leaving Boston, and it is largely on this account that mention of it is made here, in the hope that it may be again tested at a later eclipse.

Report on the Changes in Declination of the Magnetic Needle during the Eclipse.

By GEORGE L. HOSMER.

The magnetometer was set up on the summit of a hill to the northeast of the eclipse station, in a hut built of wooden poles, bound together with rattan and thatched with grass. The tripod was set on wooden pegs, driven firmly into the ground. About 1,200 feet to the south a mark was set up, so that it could be seen with the telescope in the same position it would occupy during observations. The azimuth of the mark was found by triangulation from the true meridian established by the transit instrument. It was found to be 0° 53′ 17″ (S.W.). A brass lamp was placed at one side of the instrument, for illuminating the scale during totality. The magnet was suspended by new silk threads, which had been soaked in glycerine on May 16th. All iron or steel (except the watch) was removed to a distance of at least 50 feet. The watch kept the mean local time of the meridian of the transit pier. The vertical cross hair was pointed on the mark, and the magnet then suspended. Scale readings were taken every five minutes,

from 9*h.* 45*m.* A.M. to 2*h.* 15*m.* P.M. Additional readings halfway between were taken between 10*h.* 30*m.* and 2 P.M. Temperatures were read every ten minutes. At the close of the observations, the pointing on the mark was examined and found to be the same as at

FIG. 13. — MAGNETOMETER SHELTER.

the beginning. The scale reading of the axis as found from two observations on May 18th was 40.8*d.*

The value of one division of the scale is 1′.76. From a survey, the magnetic station was found to be 19″.0 north and 10″.2 east of the transit pier. The elevation of the station is 1,752 feet. Increasing scale readings correspond to increasing azimuth of magnet (in direction S W N E).

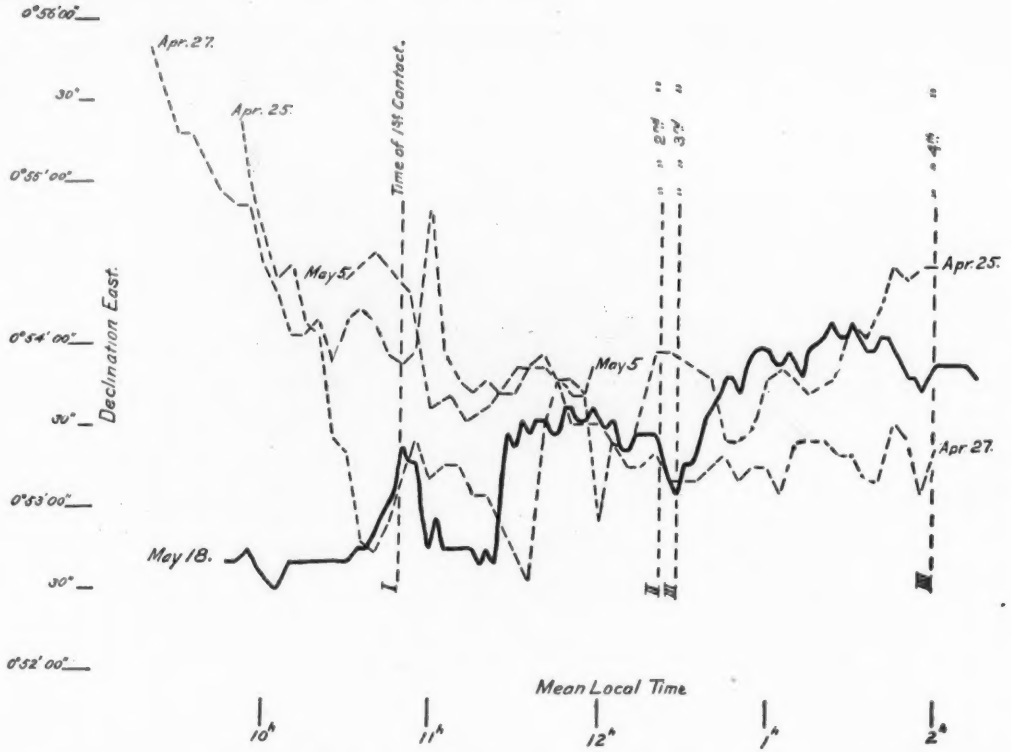


FIG. 14. — CURVES SHOWING CHANGES IN DECLINATION OF MAGNETIC NEEDLES AT SAWAH LOENTO, ON APRIL 25, 27, MAY 5, AND MAY 18, 1901.

TABLE OF SCALE READINGS. SAWAH LOENTO, MAY 18, 1901.

M L. T.	Temperature.	Scale.		Mean.
		L.	R.	
9 45		....	....	....
.....		37.0	43.9	40 45
50		37.2	43.7	40.45
55		38 2	42.8	40.5
10 00		38 9	41.9	40.4
	25.9°			
05		39.3	41.4	40.35
10		39 7	41.2	40 45
15		40.0	40.9	40.45
	26.0°			
20		40.2	40.7	40.45
25		40 2	40.7	40 45
30		39.7	41 2	40.45
	26 2°	39.9	41.0	40.45
35		40 0	41.0	40 5
		40.1	40.9	40 5
40		40 2	40.9	40 55
		40.3	40 9	40 6
45		40.4	40 9	40.65
		40.5	40.9	40.7
50		39.9	41.8	40.85
	26 5°	40.0	41.6	40.8
55		40.1	41.5	40.8
11 00		40.1	41.1	40.6
		40.1	40.9	40.5
11 00		40.1	40.9	40.5
	26.6°	40.3	40.9	40.6
05		40 3	40.7	40.5
		40 3	40 7	40.5
10		40 4	40.6	40.5
		39.2	41.8	40.5
15		39.4	41.6	40.5
	26.8°	39.6	41.3	40.45
20		39 9	41.1	40.5
		39.9	41.0	40.45
25		40.2	41.1	40.65
	27.0°	40.4	41 4	40.9
30		40 5	41.2	40.85
		40.7	41.2	40.95
35		40.7	41.5	40.9
	27.0°	40.8	41.1	40.95
40		40 9	41.0	40.95
		40.4	41.4	40.9
45		40 5	41 3	40.9
		40.7	41.3	41.0
50		40.8	41.2	41.0
	27.0°	40 8	41.1	40.95
11 55		40 8	41.1	40.95
	26.8°	40 3	41.7	41.0
12 00		40.4	41.5	40.95
		40.5	41.3	40.9
05		40.6	41.3	40 95
		40.6	41.1	40.85
10		40.6	41.1	40.85
	26 6°	39.8	42.0	40.9
15		40.0	41.8	40.9

TABLE OF SCALE READINGS. SAWAH LOENTO, MAY 18, 1901. — *Concluded.*

M. L. T.	Temperature.	Scale.		Mean.
		L.	R.	
	26.4°	40.1	41.7	40.9
20		40 2	41.6	40.9
		40.3	41.4	40.85
25		40.3	41.2	40.75
	26.0°	40 4	41.0	40.7
30				
	25.9°	37.4	44.2	40 8
35		37.6	44.0	40.8
40		38.2	43.5	40.85
		38 8	43 1	40.95
45		39.2	42 8	41.0
		39 7	42.4	41.05
12 50		39.9	42 3	41.1
	25.5°	40.1	42 1	41.1
55		40.2	41.9	41.05
		40 4	41.9	41.15
1 00		40 6	41.8	41.2
	25.6°	40.7	41.7	41 2
05		40.9	41.5	41.2
		40.9	41.4	41 15
10	25.6°	40.9	41 4	41.15
		41 0	41.4	41 2
15		41.0	41 3	41.15
20	25.6°	41 0	41 2	41 1
		40.2	42 2	41 2
25		40 6	41.9	41.25
		40.8	41.8	41.3
30		40.9	41.6	41.25
		40.9	41 6	41 25
35		41 0	41 6	41.3
		41.0	41.5	41 25
40		41.0	41.4	41 2
		39.0	43.4	41.2
45	26.1°	39 5	43 0	41.25
		39.9	42.6	41.25
50		40.1	42 3	41.2
		40 2	42 1	41.15
55		40 3	41.9	41.1
		40.4	41 8	41.1
2 00		40.5	41 6	41.05
05		40.7	41.5	41 1
10		40.8	41.5	41 15
15		40.9	41.4	41.15
		41.0	41.3	41.15
		41.0	41.2	41.1

In the accompanying plot, Figure 14, the heavy line is the curve of May 18th. The dotted lines are curves obtained on three different days before May 18th. These observations were made at a different station, so that they are not strictly comparable with the curve obtained on the day of the eclipse; but they all show that ordinarily

the declination is decreasing during that part of the day, while on May 18th the declination increased.

In addition to the above, the following magnetic observations were made at Sawah Loento:

April 27, 1901.	Decl. = 0° 56.4′ E. of N.
May 4, 1901.	Dip. = 20° 33.4′.

Pendulum Observations Made in Connection with the Massachusetts Institute of Technology Eclipse Expedition to Sumatra.

By GEORGE L. HOSMER.

The program of gravity observations made in connection with the eclipse expedition is as follows:

The three pendulums of "Apparatus B" were swung at the office of the United States Coast and Geodetic Survey at Washington, between February 5th and February 7th, 1901. At Sawah Loento, Sumatra, during the time occupied in preparing for the eclipse, a set of observations was made between May 6th and May 8th. The party sailed from Padang on May 29th, and went directly to Singapore. At this point two sets of swings were made — the first between June 7th and June 10th; the second between June 12th and June 14th. The second set was made on the same spot occupied by the "Transit of Venus Party" in 1882; the first was made under practically the same conditions. After returning to the United States, the pendulums were again swung at the Coast and Geodetic Survey Office, between October 8th and October 10th.

During the February observations at Washington, chronometer No. 1823 Negus was used for observing the coincidences. The time was determined by transits of about eight stars, recorded on a chronograph. On account of a leakage of the receiver during the last swing, due to improper sealing of the joint, this set is incomplete. There was so little time remaining before the date of sailing that a complete set could not be obtained.

At Sawah Loento, Sumatra, the pendulum apparatus, transit, and chronograph were all placed in a small bamboo hut. The pendulum case was mounted on a solid brick pier, 75 cm. square, 30 cm. above the surface and 75 cm. below the surface. The flash apparatus was set on a small brick pier of convenient height. Time was determined

by star transits, observed by a $2\frac{1}{2}$-inch meridian telescope, mounted on a brick pier. The observations were recorded by chronograph. The sets consisted of eight or more stars, chosen so as to determine the instrumental errors. The chronometer, Bond No. 541, was placed

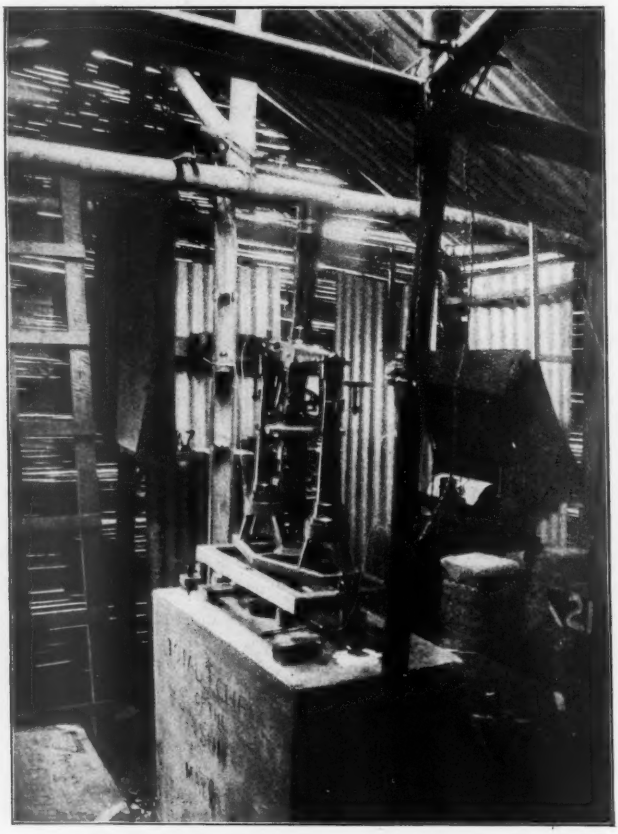


FIG. 15. — TRANSIT AND CHRONOGRAPH AT SAWAH LOENTO STATION.

on a pier, and was not disturbed during the series. At this station there was no leakage, and the swings were satisfactory. The approximate position of the station is: latitude, 0° 41′ 40″ south; longitude, 100° 46′ 40″ east. The altitude above sea level = 1,246 feet. The sketch, Figure 4, shows the pendulum station and vicinity.

At Singapore the apparatus was set up in the laboratory of the

General Hospital. This room has a solid tiled floor. The receiver was placed near a corner of the room, so as to be near the supporting columns. The pier built by the Coast Survey party in 1882 was found to be in good condition, but it was not necessary to use it.

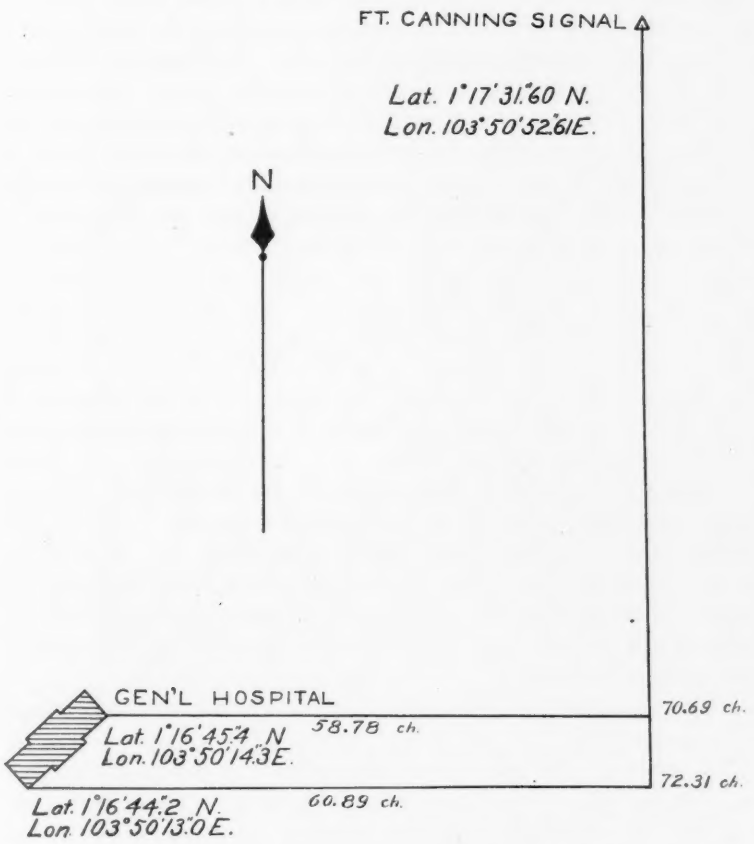


FIG. 16. — DIAGRAM SHOWING LOCATION OF GENERAL HOSPITAL BUILDING AT SINGAPORE. PENDULUM STATIONS IN EAST AND SOUTH CORNERS OF HOSPITAL BUILDING.

It was found that an excellent time service was carried on at the observatory. Mr. R. S. Frye, the observer, kindly offered to make special observations for our work. The rate of No. 541 was determined by comparison with the standard sidereal clock (Kullberg 5364), two

mean time chronometers being used for making the comparisons. Sidereal chronometer, Bliss and Creighton No. 1307 was also carried, and compared through the mean time chronometers. Care was taken that chronometer No. 541 should not be disturbed during the set. After this first set was completed, it was discovered that the laboratory in 1882 was at the other end of the building, in a similar room. Although the difference would be very slight, still it was decided best to occupy the very same spot used by the "Transit of Venus Party," and thus have two sets of swings as a check. The first set was made in the east corner and the second set in the south corner of the building. The following information was furnished by the office of the Colonial Engineers. The position of the flagstaff at Fort Canning is as follows:

Lat. 1° 17′ 31.6″ N.
Long. 103° 50′ 52.61″ E.

(From Trig. Chart, 1893.)

The accompanying diagram, Figure 16, shows the position of the Hospital building with reference to the flagstaff, as furnished by the Colonial Engineers' Office.

During the October observations at Washington, chronometer, Blunt and Nichols No. 353 was used (loaned by United States Geological Survey). No chronograph was available, so eye and ear observations had to be made. For this reason it was necessary to move the chronometer from the pendulum room to the observatory. The swings of this set were satisfactory so far as the pendulum apparatus was concerned.

The apparatus used was the set of half-second "invariable" pendulums, belonging to the United States Coast Survey, known as "Apparatus B." It consists of three half-second pendulums, marked B4, B5 and B6. These are swung in an air-tight case, and are supported on a knife edge fastened to the case. An agate plane is set into each pendulum at the point of support, and rests on the knife edge. A manometer is placed within the case for measuring the pressure of the air. A thermometer is attached to a special pendulum, called a "dummy" or "temperature pendulum," which is hung inside the case, beside the swinging pendulum. There is a metallic contact between the thermometer bulb and the "dummy," made by means of filings of the alloy of which the pendulums are made. This

is done in order to obtain, as nearly as may be, the temperature of the swinging pendulum. A second thermometer is suspended within the case, in order to check the first thermometer.

The "flash apparatus" is a mechanism for throwing a flash of light on to two small mirrors — one on the pendulum, the other beside it on the case. A small lamp at one side throws light on to a mirror within the apparatus. This mirror sends the beam of light through a narrow slit to the mirrors in the pendulum case. From these two mirrors it is reflected to the observing telescope at the top of the apparatus. Behind the mirror inside the apparatus is an electro-magnet, the armature of which is attached to a slide, which moves in front of the slit, so that in a certain position the slit is open for an instant. The "flash apparatus" and the chronometer are both included in an electric circuit. The chronometer breaks the circuit at the end of every second (or every two seconds). When the circuit is broken, the movement of the armature causes the slit to be opened for an instant, and a flash of light is sent to the pendulum and reflected by the two mirrors. The flash on the fixed mirror is always in the same position, while that on the pendulum changes continually, depending upon the position of the pendulum at the end of the second. In a certain position of the pendulum the flashes will coincide. When the pendulum moves away from this position and returns to it again, it loses just one oscillation, compared with the chronometer beats. From this interval the period, in terms of the seconds of the chronometer, can be found. In connection with this observation it is necessary to know (1) the arc of oscillation at the beginning and end of the swing; (2) the pressure of the air in the receiver; (3) the temperature of the pendulum; (4) the movement of the support; and (5) the rate of the chronometer on true sidereal time.

In this series of observations the same plan was followed out as has been used by the Coast and Geodetic Survey, viz., the swings were begun in the evening immediately after time observations, and the three pendulums swung in the direct and reversed positions, each swing lasting about eight hours, so that the last one ended immediately after time observations two nights later. In case star observations could not be obtained at the time, the swings were continued until they could be obtained.

The uncorrected period is found by the relation:

$$P = \frac{s}{2s - 1}$$

where s is the number of seconds in one interval between successive coincidences of the flash. A sufficient number of coincidences is observed to enable the observer to estimate the total number of coincidences that have taken place during the eight hours. This period is then corrected as follows:—

(1) Reduced to infinitely small arc.
(2) " " temperature 15° C.
(3) " " pressure 60^{mm} at 0° C.
(4) " " rigid support.
(5) " " true sidereal time.

The formulæ for these corrections are:

$$(1)\ \text{Arc corr.} = -\frac{PM}{32} \cdot \frac{\sin(\phi + \phi')\sin(\phi - \phi')}{\log\sin\phi - \log\sin\phi'}.$$

M = modulus of common log. system.
ϕ and ϕ' = the initial and final arcs.
P = the period.

(2) Temp. corr. $= +\ .000\ 008\ 37\ P(15° - T°)$.
$T°$ = observed temperature.

$$(3)\ \text{Pressure corr.} = +\ .000\ 000\ 101\ \left[60 - \frac{Pr.}{1 + .00367\ T°}\right].$$

(4) Flexure corr. $= -\ .000\ 000\ 65\ D$.
D = movement in microns.

(5) Rate corr. $= +\ .000\ 011\ 574\ R.\ P.$
R = daily rate on sidereal time; + if losing, − if gaining.

For computing g, we have:

$g_o = \frac{P_w^{\,2}}{P_o^{\,2}}\, g_w$, where P_w is the period at Washington, P_o the observed period, and g_w the absolute value of g at Washington.

TABLE A. — CHRONOMETER RATES.

STATION.	INTERVAL.	CHRONOMETER (rate on sidereal time).		
		No. 1823	No. 541	No. 353
Washington	Feb. 5–7.	+ 4.^{s}80	.....	.....
Sawah Loento	May 6–8.	.....	+ 2^s.21	.....
Singapore	June 7–8.	.....	+ 4.87	.....
Singapore	June 9–10.	.....	+ 4.69	.....
Singapore	June 12–14.	.....	+ 4.50	.....
Washington	Oct. 8–10.	.....	.....	+ 0.^{s} 27

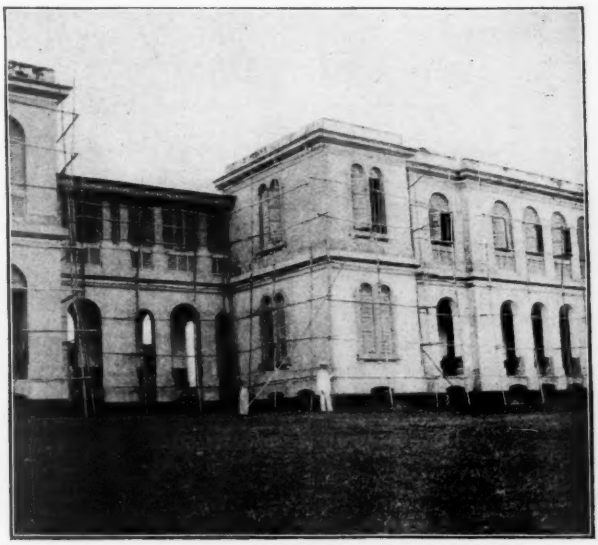


FIG. 17. — SOUTH CORNER OF GENERAL HOSPITAL BUILDING, SINGAPORE.
Pendulums were swung in the corner near which the man is standing.

TABLE B. — WASHINGTON, D.C. FEBRUARY, 1901.

Swing.	Pendulum.	Position.	Knife edge.	Date. 1901.	Coincidence Interval.	Total Arc. Initial.	Total Arc. Final.	Corrected temperature. C.	Pressure at 0° C.	Period Uncorrected.	Corrections. 7th Decimal Place. Arc.	Temperature	Pressure.	Rate. No. 1823.	Flexure.	Period Corrected.
									mm.							
1	B4	D	I	Feb. 5–6.	329.58	52′	17′	9.70°	59.6	.5007673	— 8	+ 213	+ 0	+ 278	— 20	.5008136
2	B4	R	I	Feb. 6.	329.22	52′	19′	9.25°	72.4	7681	— 8	+ 241	— 12	+ 278	— 20	8160
3	B5	D	I	Feb. 6.	370.88	52′	17′	9.10°	70.4	6750	— 8	+ 247	— 10	+ 278	— 20	7237
4	B5	R	I	Feb. 6–7.	374.88	52′	15′	8.57°	72.9	6754	— 7	+ 269	— 13	+ 278	— 20	7261
5	B6	D	I	Feb. 7.	422.40	51′	31	8.02°	61.3	5926	— 11	+ 294	— 1	+ 278	— 20	6466
6	....	..	..	....	.....	..	..	....	....	.....	..	....	..	....	..	.....
														Mean		.5007288

TABLE B. — SAWAH LOENTO, SUMATRA.

Swing.	Pendulum.	Position.	Knife edge.	Date. 1901.	Coincidence interval.	Total Arc. Initial.	Total Arc. Final.	Corrected temperature. C.	Pressure at 0° C.	Period Uncorrected.	Corrections. 7th Decimal Place. Arc.	Temperature.	Pressure.	Rate. No. 541.	Flexure.	Period Corrected.
									mm.							
1	B4	R	I	May 6–7	180.02	52′	10′	24.55°	68.6	.5013926	— 5	— 400	— 9	+ 128	— 6	.5013634
2	B4	D	I	May 7	180.78	52′	10′	25.40°	51.3	3867	— 5	— 436	+ 9	+ 128	— 6	3557
3	B6	D	I	May 7	202.30	53′	16′	27.45°	63.1	2264	— 7	— 522	— 3	+ 128	— 6	1858
4	B6	R	I	May 7–8	204.49	53′	10′	24.00°	77.0	2133	— 6	— 377	— 17	+ 128	— 6	1855
5	B5	D	I	May 8	192.83	53′	19′	24 80°	59.6	2998	— 8	— 411	0	+ 128	— 6	2701
6	B5	R	I	May 8	191.20	54′	19′	26.10°	53 4	3110	— 8	— 465	+ 7	+ 128	— 6	2766
														Mean		.5012728

TABLE B. — SINGAPORE, STRAITS SETTLEMENTS, EASTERN CORNER OF BUILDING.

Swing.	Pendulum.	Position.	Knife edge.	Date. 1901.	Coincidence interval.	Total Arc. Initial.	Total Arc. Final.	Corrected temperature. C.	Pressure at 0° C.	Period Uncorrected.	Corrections. 7th Decimal Place. Arc.	Temperature.	Pressure.	Rate. No. 541.	Flexure.	Period Corrected.
									mm.							
1	B4	D	I	June 7	183.58	58′	17′	28.60°	55.2	.5013655	— 8	— 570	+ 5	+ 282	— 12	.5013352
2	B4	R	I	June 7–8	183.64	58′	16′	28.60°	52.7	3788	— 8	— 570	+ 7	+ 282	— 12	3487
3	B5	D	I	June 8	196.14	52′	11′	28.85°	56.5	2650	— 5	— 581	+ 3	+ 282	— 12	2337
4	B5	R	I	June 9	196.49	52′	15′	28.15°	49.9	2628	— 7	— 551	+ 10	+ 272	— 12	2340
5	B6	D	I	June 9	208.79	52′	16′	28.25°	56.0	2002	— 7	— 555	+ 4	+ 272	— 12	1704
6	B6	R	I	June 9–10	209.80	55′	17′	27.85°	54.3	1825	— 8	— 538	+ 6	+ 272	— 12	1545
														Mean		.5012461

TABLE B. — SINGAPORE, STRAITS SETTLEMENTS, SOUTH CORNER OF BUILDING.

Swing.	Pendulum.	Position.	Knife edge.	Date. 1901.	Coincidence interval.	Total Arc. Initial.	Total Arc. Final.	Corrected temperature. C.	Pressure at 0° C.	Period Uncorrected.	Corrections. 7th Decimal Place. Arc.	Temperature.	Pressure.	Rate. No. 541.	Flexure.	Period Corrected.
									mm.							
1	B4	D	I	June 12–13	184.38	52′	17′	26.95°	55 5	.5013459	— 8	— 501	+ 4	+ 261	— 12	.5013203
2	B4	R	I	June 13	184.23	51′	16′	26.95°	55.3	3607	— 7	— 501	+ 5	+ 261	— 12	3353
3	B5	D	I	June 13	196.69	52′	16′	27.30°	52.9	2870	— 7	— 515	+ 7	+ 261	— 12	2604
4	B5	R	I	June 13–14	197.07	53′	17′	26.85°	53.0	2591	— 7	— 496	+ 7	+ 261	— 12	2344
5	B6	D	I	June 14	209.90	52′	16′	26.70°	57.3	1939	— 7	— 490	+ 3	+ 261	— 12	1694
6	B6	R	I	June 14	209.80	53′	14′	27.20°	56.2	1832	— 7	— 511	+ 4	+ 261	— 12	1567
														Mean		.5012461

TABLE B. — WASHINGTON, D.C. OCTOBER, 1901.

Swing.	Pendulum.	Position.	Knife edge.	Date. 1901.	Coincidence interval.	Total Arc. Initial.	Total Arc. Final.	Corrected temperature. C.	Pressure at 0° C.	Period Uncorrected.	Corrections. 7th Decimal Place. Arc.	Temperature.	Pressure.	Rate. No. 353.	Flexure.	Period Corrected.
									mm.							
1	B4	D	I	Oct. 8–9	307.84	54′	19′	16.13°	63.1	.5008134	— 8	— 47	— 3	+ 15	— 20	.5008076
2	B4	R	I	Oct. 9	305 20	54′	21′	16.88°	61.2	8205	— 8	— 79	— 1	+ 15	— 20	8112
3	B5	D	I	Oct. 9	341.91	54′	21′	17.33°	60.7	7250	— 8	— 98	— 1	+ 15	— 20	7138
4	B5	R	I	Oct. 9–10	345.62	62′	09′	17.83°	61.4	7244	— 7	— 118	— 1	+ 15	— 20	7113
5	B6	D	I	Oct. 10	380 26	53′	19′	18.28°	57.3	6583	— 8	— 137	+ 3	+ 15	— 20	6436
6	B6	R	I	Oct. 10	382.59	59′	21′	18.83°	58.9	6543	— 10	— 161	+ 1	+ 15	— 20	6368
														Mean		.5007207

TABLE C. — SUMMARY OF CORRECTED PERIODS.

STATION.	DATE. 1901.	PERIODS.			
		B_4.	B_5.	B_6.	Mean.
Washington	Feb. 5–7	.5008148	.5007249	.5006466	.5007288
Sawah Loento ...	May 6–8	.5013595	.5012734	.5011856	.5012728
Singapore	June 7–10	.5013420	.5012338	.5011624	.5012461
Singapore	June 12–14	.5013278	.5012474	.5011630	.5012461
Washington	Oct. 8–10	.5008094	.5007125	.5006402	.5007207

TABLE D. — VALUES OF g FROM OBSERVATIONS AT SAWAH LOENTO AND SINGAPORE.

STATION.	g	LATITUDE.	LONGITUDE.	ALTITUDE.
Washington	980 098			
Sawah Loento...	977.941	$-0^\circ\ 41'\ 40''$ [1]	$-100^\circ\ 46'\ 40''$ [2]	1.246 feet.
Singapore	978.045	$+1^\circ\ 16'\ 44.2''$ (*a*)	$-103^\circ\ 50'\ 13.0''$ (*a*)	45 feet

[1] By observation. [2] From topographical map of Sumatra.

(*a*) South corner (same point as that used by "Transit of Venus party.")

NOTE. — The February and October observations at Washington are given equal weight in the above computation.

STAR OBSERVATIONS FOR TIME AT SAWAH LOENTO, SUMATRA, MAY 6, 1901.

Station, Sawah Loento. Date, May 6, 1901. Observer, G. L. H. Chronometer, Bond 541.

41 L. Min. Clamp E			/ Leonis. E		P³ Leonis. E			d Crateris. E		τ Leonis. W		ξ Hydræ. W		υ Leonis. W		χ Urs. Maj. W	
50.0			27.0	7.0	55.5			27.5	8.0	42.0	40.5	.115		18.5	18.0	13.0	24.0
18.0																	
		.320	23.0	11.0	15.0			28.0	7.0	30.5	34.0	.065		12.0	24.0	21.0	16.5
+32.0		.405															
			50.0	18.0	40.5			55.5	15.0	11.5	6.5	2).180		30.5	42.0	34.0	40.5
.01		2).725			.01					.01	.01						
												—.090					
+.320		+.362			-405					—.115	—.065						
			$b_e = +.362$									$b_w = -.090$					
10	51	37.18	57	40.00	11	15	28.60	28	00.00	36	27.55	41	41.07	45	29.63	54	12.92
		41.32		44.00			32.63		04.00		31.68		45.80		33.80		19.15
		45.95		48.30			36.72		08.28		35.75		50.60		37.80		25.35
		54.86		56.60			44.85		16 65		44.12	42	00.58		46.24		37.85
		59.44	58	00.94			49.05		21.08		48 42		05.52		50.46		44.40
	52	03.65		04.86			52.75		24.96		52.72		10.60		54.77		51.00
		08.38		09.40			57.30		29.45		56 70		15.20		58.65		56.72
		13.10		13.70		16	01.60		33.70	37	00.80		20.00	46	02.78	55	03.10
		22.16		22.07			09.67		42.30		08.85		29.32		10.85		15.00
		26.53		26.43			13.85		46.70		13.28		34.44		15.15		21.35
		31.09		30.40			18.00		50.85		17.05		39.04		19.05		27.40
	52	03.96	58	05.15		15	53.18	28	25.27	36	52.45	42	10.20	45	54.47	54	50.38
ε		— .02		— .02			— .02		— .02		— .02		— .02		— .02		— .02
3 b		+ .36		+ .36			+ .36		+ .36		— .09		— .09		— .09		— .08
τ		— .06		— .05			— .03		.00		+ .01		+ .02		+ .03		+ .04
ε 10	52	04.24	58	05.44	11	15	53.49	28	25.61	36	52.35	42	10.11	45	54.39	54	50.32
α 10	38	04.42	44	05.62		01	53.69	14	26.00	22	53.32	28	10.72	31	55 39	40	52.22
α-t_1	13	59 82	13	59.82		13	59.80	13	59.61	13	59.03	13	59.39	13	59.00	13	58.10

COMPUTATION OF CHRONOMETER CORRECTION FROM STAR OBSERVATIONS AT SAWAH LOENTO, MAY 6, 1901.

	Star.	Pos.	$\alpha - t_1$	C	A	Cc	Aa	ΔT α-t_1, -Cc-Aa.	v	
	41 L. Min.	E	59.82	— 1.09	— .45	— .34	— .19	—59.29	.09	
	l Leonis	E	59.82	— 1.02	— .21	— .33	— .09	.40	.02	
	P3 Leonis	E	59.80	— 1.00	— .05	— .33	— .02	.45	.07	$\Delta T = -13^m\ 59^s.37$
	δ Crateris	E	59.61	— 1.03	+ .24	— .33	+ .10	.38	.00	at $11^h\ 30^m$
	τ Leonis	W	59.03	1.00	— .07	+ .33	+ .05	.41	.05	
	ν Leonis	W	59.00	1.00	— .00	+ .33	.00	.33	.03	
	χ Urs. Maj.	W	58.10	1.49	— 1.13	+ .50	+ .76	.36	.00	
	ξ Hydræ	W	59.39	1.16	+ .59	+ .34	— .40	.33	.03	
			$\alpha - t_1$	C	A	Cc	α-t_1,-Cc	Aa	$\alpha - t_1$,-Cc -Aa	c = + .20
1st approx.	Mean of N stars,	E	59.81	— 1.04	— .24	— .21	59.60	— .10	—59.50	a_e = + .417
	Mean of S stars,	E	59.61	— 1.03	+ .24	— .21	59.40	+ .10	—59.50	
	Mean of N stars,	W	58.71	+ 1.16	— .40	+ .23	58.94	+ .27	—59.21	a_w = — .687
	Mean of S stars,	W	59.39	+ 1.16	+ .59	+ .23	59.62	— .40	—59.21	
2d approx.	Mean of N stars,	E				— .34	59.47	— .10	—59.37	c = + .330
	Mean of S stars,	E				— .34	59.27	+ .10	—59.37	a_e = + .417
	Mean of N stars,	W				+ .38	59.09	+ .27	—59.36	a_w = — .667
	Mean of S stars,	W				+ .38	59.77	— .40	—59.37	

EXAMPLE OF PENDULUM OBSERVATIONS.

Washington, D.C. February 6, 1901. Pendulum B5 reversed. Knife edge I.

	Coincidences.	Pressure.	Temperature.	Arc.
		mm.		mm.
U	9 — 24 — 38	37.5	9.2° C.	4.5
		37.5		
D	30 — 40	75.0		
U	37 — 05			
D	43 — 05			
	.....			
	.....			
	.....		(February 7 A.M.)	
	.....			
		mm.		mm.
D	16 — 59 — 28	38.0	8.4°	1.3
		38.0		
U	17 — 06 — 33	76.0		
D	12 — 06			
U	19 — 06			
D	24 — 37			

Total time interval = 27,703.6s.
Number coincidences = 37.
Time in one double interval = 748.75.
Time in one interval = 374.38.
Period = .5006754.

LATITUDE OBSERVATIONS.

Sawah Loento, Sumatra.

Date.	Pair. Gr. 10 Yr. Cat.	Latitude.
May 14, 1901.	{ 1712 { 1732	— 0° 41′ 41.42″
May 14, 1901.	{ 1784 { 1791	— 0° 41′ 37.37″
May 14, 1901.	{ 1884 { 1891	— 0° 41′ 41.27″
		Mean = — 0° 41′ 40.02″

A STUDY OF CERTAIN SHADES AND GLOBES FOR ELECTRIC LIGHTS AS USED IN INTERIOR ILLUMINATION.

By WILLIAM LINCOLN SMITH, S.B.

Part II.

[*Continued from Vol. XIII, page 176.*]

A. General Considerations.

In the first part of this paper[1] were given distribution curves of incandescent lamps fitted with various types of shades or globes, and the efficiency of the several combinations was determined by finding the Mean Spherical Candle-power and the Energy consumption in the usual manner. The Mean Spherical Candle-power is, in my opinion, the quantity by which in the last resort one must compare relative efficiencies, unless one is willing to lose himself in a maze of cross purposes and entangling specialties, among which it is exceedingly difficult to find any other simple and satisfactory basis of comparison.

Here as elsewhere, however, one must not fall into the error of making efficiency the only criterion.

There is, first, the broad and complex matter of *color effect* to be considered, since it by no means follows that because a particular effect is satisfactory in one case, it will be even bearable in another, where the same general arrangement holds, but the color scheme and character of decoration is widely different. For examination along this line we must call in the aid of the Spectro-photometer, and the corresponding section of this work is reserved for part three of this paper, the preparation of which is at present in progress.

The second point to be considered is that of *distribution of light over surfaces to be illuminated.* It is only in very rare cases that it

[1] Technology Quarterly, Vol. XIII, page 176. September, 1900.

is advisable to use modern light sources, as Welsbach mantles, acetylene gas, incandescent or arc lamps, unaccompanied by some form of diffusing shade or globe, for most frequently the source will come somewhat within the line of vision. In this case the intrinsic brilliancy must be cut down, — all the newer light sources agreeing in this: that the value of the candle-power emitted per unit of area of light-giving surface is very high. Thus the open arc may give over 25,000 C. P. to the square inch, the incandescent lamp may range from 100 to 200, acetylene gas ranges from 75 to 125, while the Welsbach mantle will vary from 20 to 25. Now, of the older light sources, the flat flame of gas gives from 4 to 8; the oil lamp, from 3 to 8, both varying widely, however; and the candle is lower still. It is safe to say that the intrinsic brilliancy should never rise above five candle-power per square inch, and personally I prefer to keep it rather lower if possible.

Thus it will be seen readily that the use of some form of diffusing shade is necessary in the great majority of cases, in order that the light may appear to radiate from a much larger surface than is the case with the bare lamp, and thus the intrinsic brilliancy be properly reduced. But the shade ought to do more than this, it should aid us from the point of view of *illumination* as distinct from *lighting*, and it is just this distinction which the great majority of persons fail to take into account. For instance, let us consider a draughting room. Suppose we hang lights on pendant cords over each drawing table; the illumination of the boards will be strong and bright, yet the room may be very badly lighted. For if the lamps are fitted with conical green paper or tin shades the whole upper part of the room will be in gloom and the worker's eyes strained as he raises them from his work and then drops them again; while if the lights are bare the conditions may be as bad, if not worse; since, if the lamps are high, it will be difficult to get light enough at the proper angle on the board, and, if low, they may easily come within the range of vision. In either case the workman will find that on raising his eyes from his work they are strained, just as when the shades were used. In the first case the iris dilated to accommodate itself to the gloom of the room as compared to the board, in the second case it contracted to accommodate itself to the presence of the small, bright light sources; so that the alternate opening and closing will finally result in serious strain, and may do irreparable

damage. We get, in other words, good illumination but very bad lighting. Now suppose this room to be lighted by concealed lamps of high power, their light being thrown on to a white diffusing surface, as a slightly arched ceiling and whitened walls, the room will be excellently lighted, but the working illumination will be bad, for we shall have approached so nearly to complete diffusion and uniformity that the result will again be strain and damage to the eye, resulting in this case from the total absence of shadow and the consequent inability of the eye to readily locate a point on the paper or to judge of distance; the strain now falling upon the focusing apparatus instead of, as previously, upon the muscles controlling the iris.

Between these two extreme cases will be found a happy mean, which may be more or less closely approximated in a variety of ways. In the room considered above, it would be found in providing a moderate general illumination by the hidden lights, and fitting each table with a small, thoroughly shaded lamp, flexibly supported, so that its rays could be directed at any desired angle upon any desired portion of the work.

Such a lay-out, however, would prove decidedly expensive, and an approximation to the result might be made by the use of larger lamps raised high and fitted with globes which would cut down the intrinsic brilliancy properly, and at the same time direct the light downward, so as to give sufficient illumination.

Accordingly, it is of great importance for one to be able to determine beforehand just what a given arrangement is going to give in the way of illuminating effects. In some cases one can say offhand that the results will be thoroughly bad. Thus, if a globe like No. 15, Part I of this paper[1] (a globe with the top half opal and the lower half clear glass cut with a many-rayed star), be used, the result will be unsatisfactory for many purposes, because the globe will produce very marked striations on a surface below.

Again, take the case of the turnip type of incandescent lamp, with the upper half silvered. If the bottom half is clear glass, the light downward will be very intense, but the illuminated surfaces will be crossed and cut up by caustics and striations of great prominence. If, on the other hand, the lower half be frosted, the light will be much reduced (which does no great harm, because almost everyone just now is carried away by the delusion that the more powerful the illumina-

[1] *Loc. cit.*

tion the better he can see, than which there is no greater error), but the illuminated surface will show no trace of striations and the result will be good.

In the cases of many other globes and shades, indeed in the great majority, it is very difficult to tell just what will be the effect, even if the distribution in the mean vertical plane (found by spinning the combination) is known. Globes of the same pattern frequently vary widely among themselves, and the distribution of a given globe varies with the azimuth, so that it is altogether too laborious to attempt a calculation, with the probability in view that it will prove fallacious in the end.

It is herein, in my opinion, that one of the greatest advantages of the Holophane glass is to be found. As Part I of this paper shows, the efficiency of the globes is excellent, the light can be thrown practically in any desired direction, and the diffusing action is practically perfect. I think that this Part will show that they also excel in the uniformity existing among individual globes of the same type, and in the precision with which they allow the determination beforehand of the results to be attained, — such precision, of course, being an important indication of scientifically correct design and careful manufacture.

B. Method of Determining the Illumination on a Surface.

Given a lamp having a definite distribution curve, and situated at a definite height above a horizontal plane, to determine the illumination at any point of the plane:

In Figure 1 (drawn full scale), let O be the centre of the lamp having the distribution curve ABE, and let MX' be the surface, drawn at a vertical distance OM, below OX, such that $K \cdot OM =$ the distance in feet of the surface below the lamp, K being the equating constant, while the candle-power along any radius, as OP, is given by $K' \cdot OB$, OB being measured in the same units as is OM, — say in centimeters.

The intensity of illumination at the point P in the horizontal plane will be:

$$e = \frac{K' \cdot OB}{(K \cdot OP)^2} \cos QPO.$$

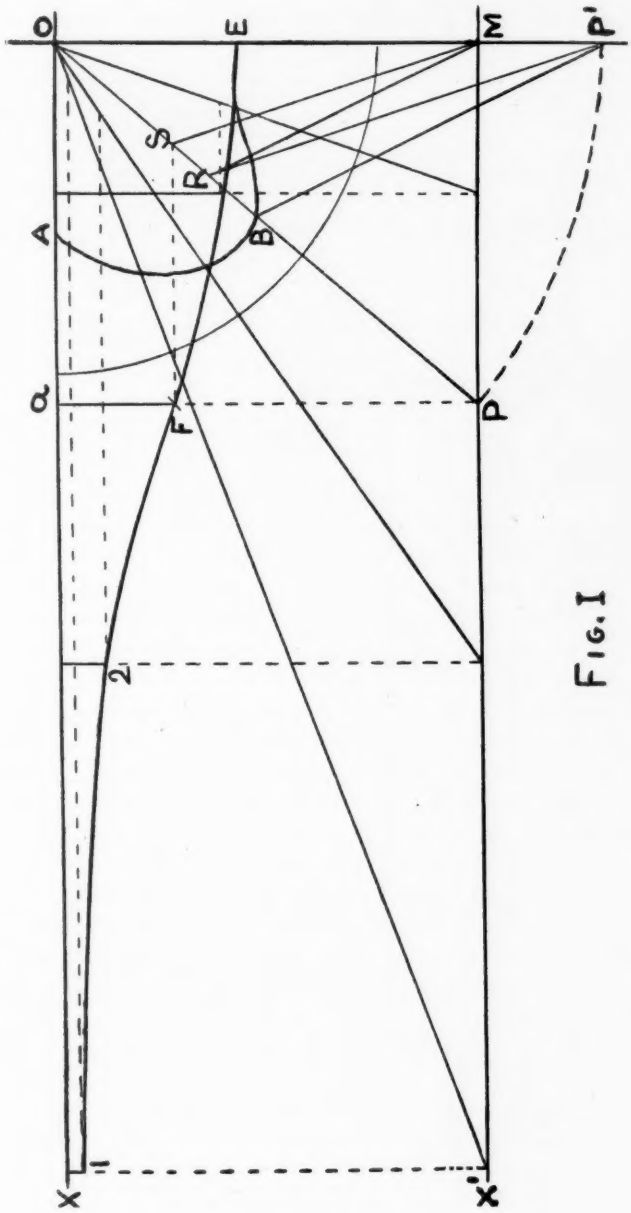


FIG. I

Now, let us lay off $OP' = OP$, join B and P', and through M draw parallel to BP', giving us point R. Connect R and P', and through M draw a parallel to RP' and we obtain a point S, and we have:

$$OS = OB\left(\frac{OM}{OP}\right)^2.$$

If through S we draw parallel to OX until we reach PQ at F, we shall have:

$$QF = OS \cos QPO = OB\left(\frac{OM}{OP}\right)^2 \cos QPO,$$

and it follows that

$$e = \frac{K'}{(K \cdot OM)^2} QF = \frac{K'}{h^2} QF,$$

h being the true height of the lamp above the plane in feet.

Continuing this process with successive radii, we obtain a curve, as 1, 2, F, E, having O as the origin, OX and OM as axes of abscissæ and ordinates respectively, such that the abscissa of any point multiplied by K gives the distance of the point from the foot of the perpendicular through the axis of the lamp, and the ordinate multiplied by K'/h^2 gives the illumination at the point in candle-feet. It is obvious that, if a given type of lamp or globe always gives the same distribution curve, that the above construction gives a plot which will be suitable for any candle-power and any height of lamp, the values of the equating constants K and K' being changed to correspond. If a point receives light from more than one source, it is sufficient to sum up the illuminations received from the several sources.

In the figure, if $K = 1$, *i.e.*, if 1 cm. = 1 ft. and $K' = 5$, *i.e.*, if 1 cm. = 5 candle-power, then the height of the lamp will be 6.5 feet above the plane, the illumination at the point P, distant 5.4 feet from the foot of the perpendicular, will be:

$$e = \frac{K'}{h^2} QF = \frac{5}{(6.5)^2}(1.8) = 0.21 \text{ candle-feet.}$$

This construction was originally due to Loppé.[1]

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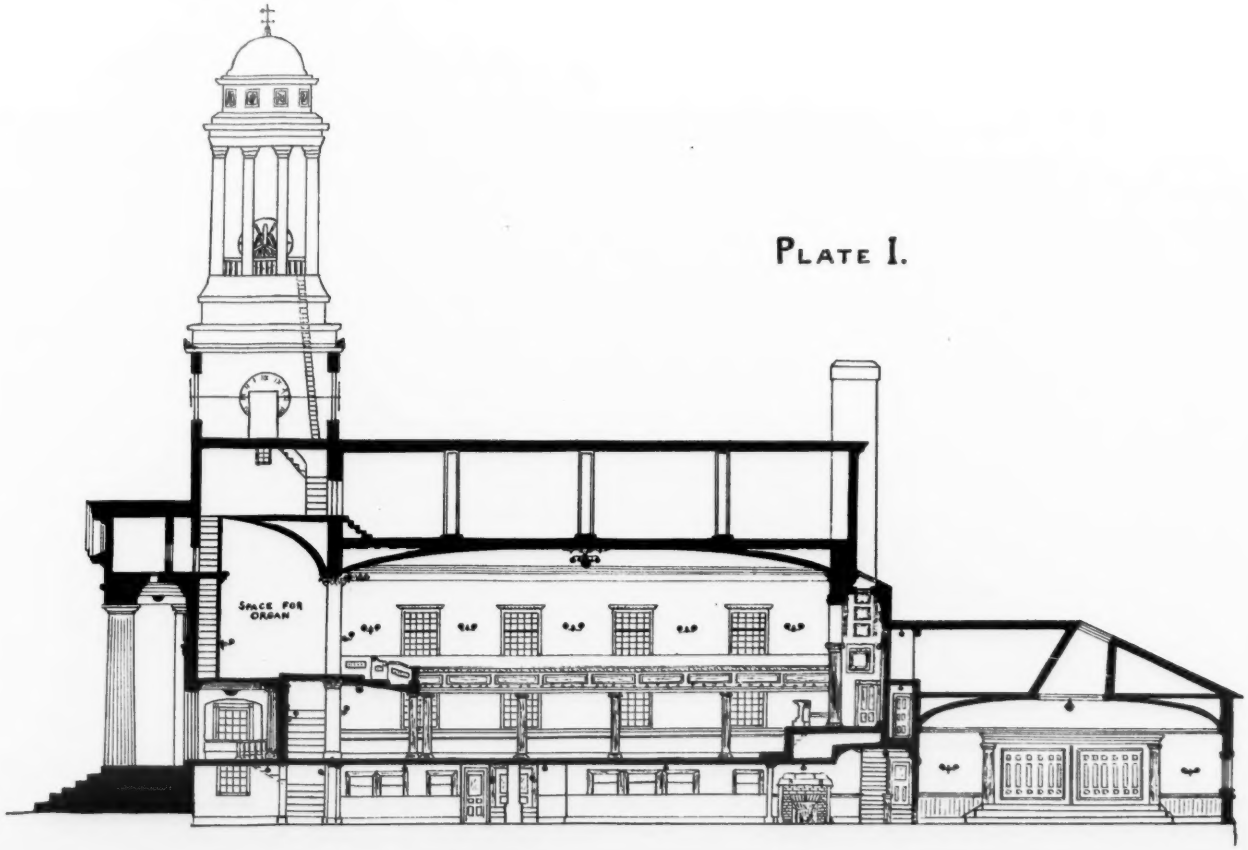
[1] *Électricien*, 1890, page 936.
Palaz and Patterson, *Industrial Photometry*, page 282.

PLATE I.



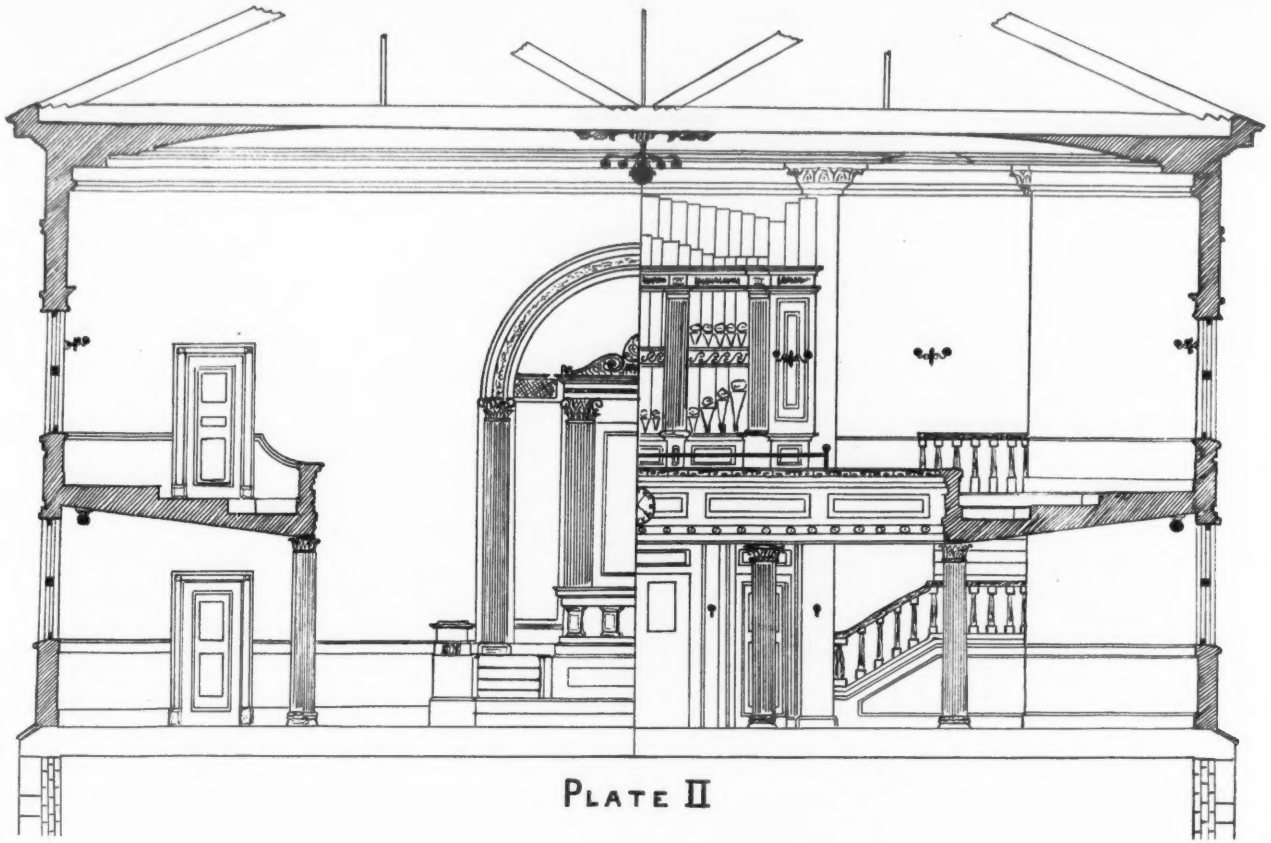


PLATE II

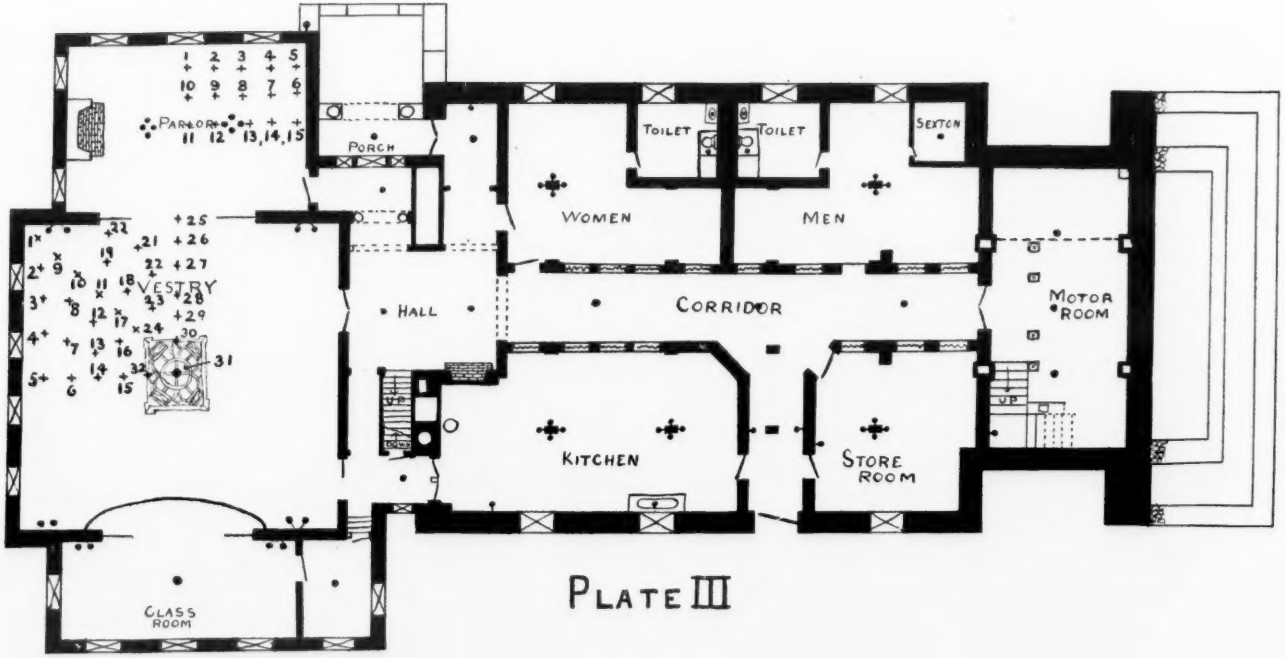

PARLOR
PORCH
VESTRY
HALL
WOMEN
TOILET
TOILET
MEN
SEXTON
CORRIDOR
MOTOR ROOM
KITCHEN
STORE ROOM
CLASS ROOM

PLATE III

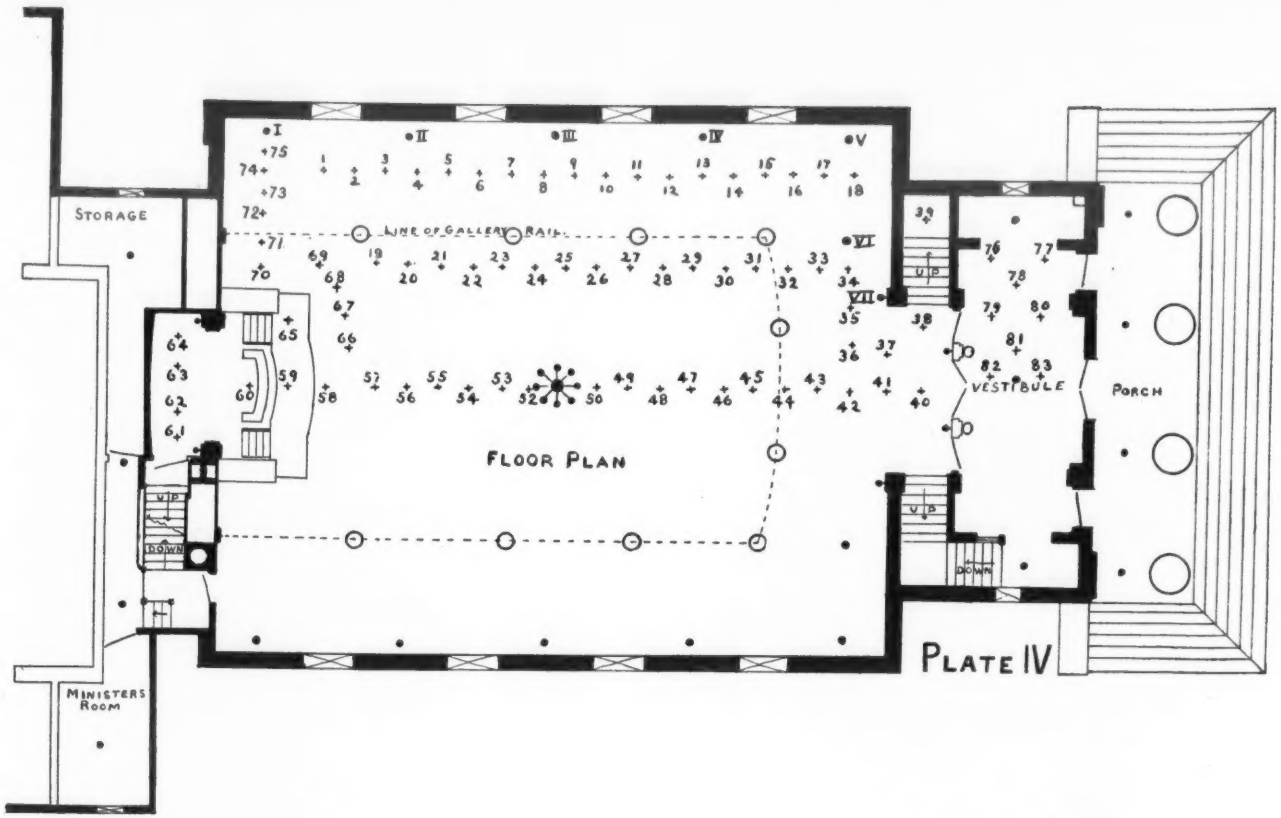

STORAGE
LINE OF GALLERY RAIL
FLOOR PLAN
VESTIBULE
PORCH
MINISTERS ROOM
UP
DOWN

PLATE IV

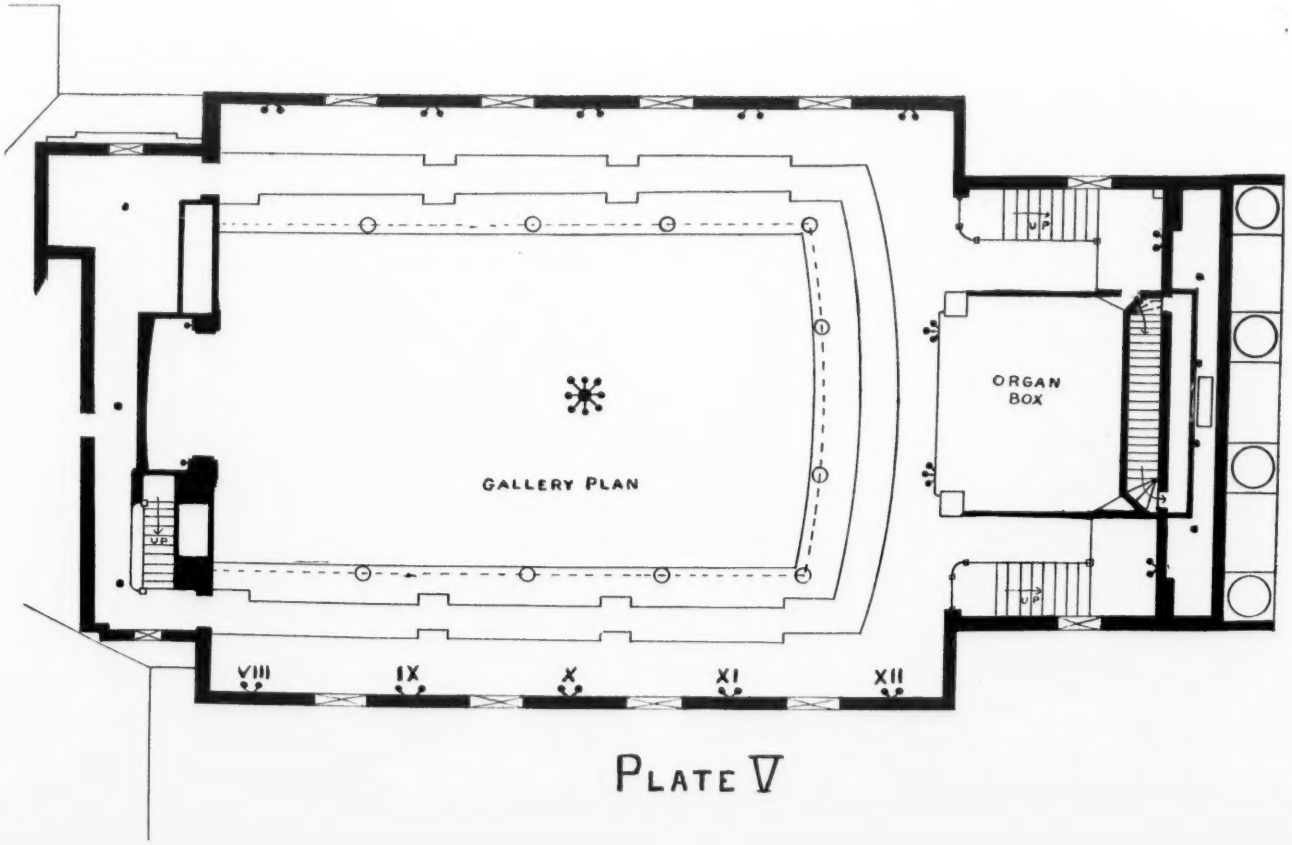
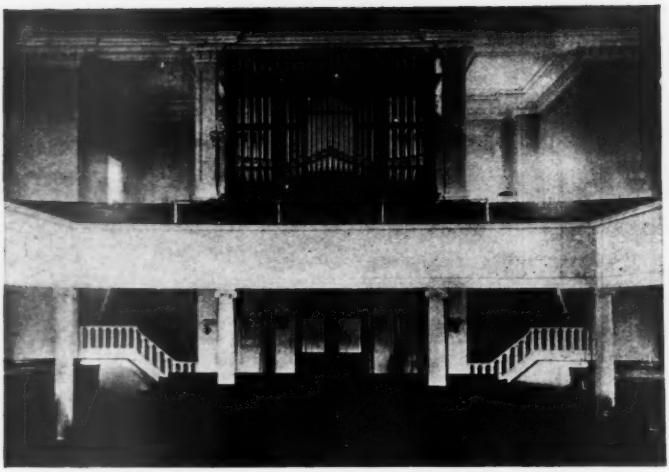


PLATE V

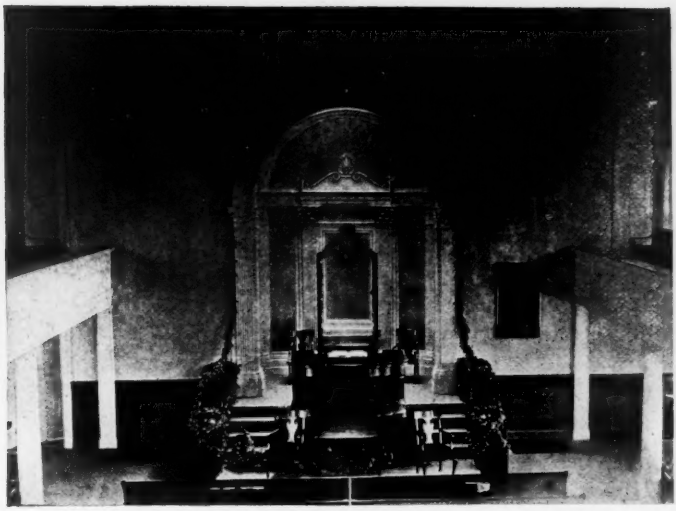
East End. Electric Light.



East End. Daylight.

Plate VI.

West End. Electric Light.



West End. Daylight.
Windows on the right hand were the brightest.

Plate VII.

C. Application of the Method.

A case to which I have recently applied this method, and which furnishes a good example of its powers, is that of the New Meeting House of the First Parish in Concord, Massachusetts.

This building is illustrated in the following plates:

Plate I, a longitudinal section of the building.

Plate II, half end elevations of the auditorium.

Plate III, a plan of the vestry and basement floor.

Plate IV, a plan of the auditorium floor.

Plate V, a plan of the galleries.

Plate VI, showing the auditorium looking east, illuminated by daylight and artificial light.[1]

Plate VII, the same, looking west.

On these plans the location of the lights is indicated by round dots, and on Plates III and IV the small crosses with attached numbers indicate the stations for which the illumination was calculated when planning the installation, and at which it was afterward determined by direct measurement.

The first step in the work was to determine the total candle-power required in the auditorium. This has, allowing for the space occupied by the galleries, organ, etc., approximately 82,000 cubic feet, requiring, on the basis of 0.02 candle-power to the cubic foot, a total of 1,640 candle-power. It was intended to use twenty No. 3555, thirty-four No. 3105 and one No. 1600 Holophane globes, having absorption, respectively, of 13.8 and 12.1 per cent., while the No. 1600, which had not been measured, was assumed to have the same as the 3555's. Allowing for the relative quantities of the several globes, this gave a mean percentage of 12.7, and, accordingly, the candle-power required would be increased to 1,848, while the amount actually used was 1,862, as this divided up better, being at the same time on the safe side.

The No. 3555 is an 8-inch ball, intended for pendant use; the No. 3105 is a 6.5-inch ball, for upright use, and the No. 1600 is a two-piece 16-inch sphere, for pendant use. The distribution curves

[1] In making the negative for the daylight picture on this plate, the plate was inadvertently reversed in the holder, so that left and right are reversed, and there has been no opportunity to make another exposure.

of the first two styles will be found in Part I,[1] pages 198 and 210, respectively. The 16-inch ball has a distribution not widely different from that of the 8-inch pendant spheres, and as but one was used, and as this one was located in the centre of a cluster, it was deemed unnecessary to make a special plot.

The two illumination curves are given in Figure 2.

The general scheme of lighting was to be — a central cluster, a row of ceiling lights on either side below the galleries, and a row of side brackets over the galleries between the windows.

In the centre of the auditorium was placed the 16-inch ball containing a 150 C. P. lamp, and around it, on a radius of 3 feet, a circle of eight of the No. 3555 balls, each containing a 50 C. P. lamp, the mean distance below the ceiling being about 3 feet.

Under the galleries, spaced midway between the windows and close against the ceiling, were placed No. 3550 balls (which are the same as No. 3555's, only fitted for a 4-inch shade holder, instead of a 5-inch), each containing a 32 C. P. lamp.

Over the galleries between the windows was placed a row of two-armed brackets, carrying No. 3105 globes with 32 C. P. lamps. The height of these brackets from the gallery floor was carefully fixed, so that the body of the auditorium was shielded, so far as possible, from the direct rays of the lights by the screen formed by the gallery rail (for the centre of the auditorium floor was going to be high in illumination at the best), while at the same time the rays were allowed to reach as far as possible under the opposite gallery, to assist in the illumination at that point. It is obvious that this consideration determined the height within very narrow limits; the illumination, however, came out very uniform, and far better than would have been obtained had the lamps been placed a foot or a foot and a half higher.

On the east wall of the building, right and left of the organ box, were placed similar brackets; on the organ front, two three-armed brackets, with similar globes and 16 C. P. lamps; on the posts at the foot of the gallery stairs and between the fly doors were put single-armed brackets, similarly fitted; while on the ceiling under the galleries, opposite the landings of the stairs, were put No. 3550 globes, as well as along the sides, only nearer to the front of the gallery. The arch behind the pulpit was lighted with five 10 C. P. frosted

[1] *Loc. cit.*

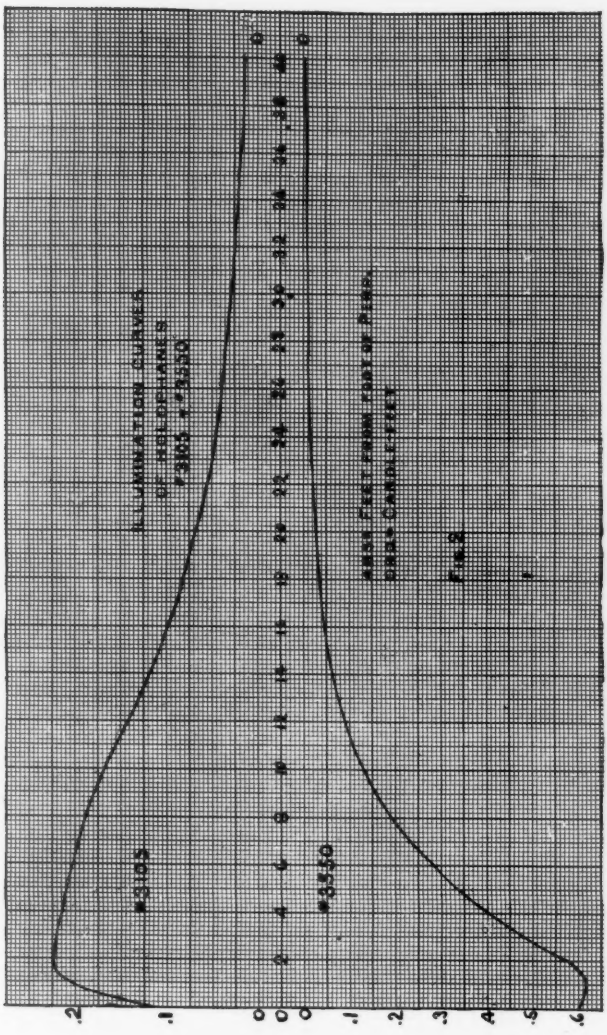

ILLUMINATION CURVES
OF PET OF PLANE
#303 & #330
AREA FACE FROM CENTER OF PLATE
AREA CARBON FILAMENT
#303
#330

FIGURE 2

lamps, wholly concealed from view, these brightening up that point but adding little to the general illumination.

The auditorium is finished in a very delicate blue tint on float-scoured plastering. The ceiling is slightly curved, finished to a light cream, the cornice white, and all woodwork and trimmings white. Behind the pulpit the finish is gold leaf, with a matt surface and white trimmings, so that the only dark portions are the blue carpet, the California red-wood pews, and the mahogany pulpit and organ case at opposite ends of the auditorium.

Some careful measurements upon finish of this nature indicated that one might safely count on an increase of about seventy-five per cent. over the calculated illumination due to diffuse reflection.

A surface upon which to lay out the illumination was now chosen at 4 feet above the floor, that being about the average height of hymn books during singing by the congregation.

Several typical points were now chosen, the lights affecting these carefully located on the building plans (though no light more than 50 feet away was considered), the distances measured, and the illumination determined. The location of the lights was then changed somewhat and the calculation repeated, the location finally chosen being that which on the average turned out best; it being decided to keep, so far as possible, between the values of 1.0 and 1.5 candle-feet.

Thus, suppose we consider Station 9, which is shown on Plate IV; the lamps affecting this are shown marked with Roman numerals on Plates IV and V. Table I shows the final estimate.

TABLE I.

Lamp No.	Distance in feet from foot of perpendicular.	Illumination in candle-feet.
1	29.0	.0045
2	15.5	.0525
3	3.0	.4800
4	11 0	.1100
5	24.5	.0200
6	Shaded	.0000
7	30.0	.0200
8	52.0	....
9	45.0	.0090
10	44 0	.0100
11	45.0	.0090
12	49.0	.0050

The illumination sums up to 0.72 candle-feet. Increase this by 75 per cent., and it is 1.26 candle-feet, a number fairly within our limits.

It was found afterward by measurement that at this station the actual illumination was 1.24 candle-feet, a difference of less than 2 per cent. This, I may add, is an exceptionally good point.

When this exact location for the lights had been determined, large scale plots of the illumination curves were made, and the illumination at seventy-five stations was calculated, to be sure that no serious discrepancies had crept in. These seventy-five stations were all on one side of the auditorium, it being assumed that the other side would be symmetrical with the first.

D. Measurement of the Illumination.

For the determination of the illumination obtained, I used a Leonhard Weber Portable Photometer.[1] The white card supplied by the makers was used and no opal screen was inserted, as it was

[1] For description, see W. F. Stine, Photometrical Measurements.

possible to get readings without one. Instead of the benzine standard belonging to the instrument, a small incandescent lamp was used. This lamp had been aged and was run at considerably less than its rated voltage, being supplied from a good-sized storage battery of three cells. The voltage on the lamp was 3.50, being maintained constant by the aid of a suitable, finely divided resistance and a carefully calibrated Weston voltmeter. This secondary standard was calibrated against a Hefner Standard lamp and a curve (Figure 3) drawn giving directly the illumination on the white card in terms of the graduated scale on the Photometer. Because of the color difference between the Hefner and incandescent lamps, it was found necessary to use the red and green diaphragms in the eyepiece during calibration, but for all the rest of the work the colors were so nearly alike that the clear eyepiece was entirely satisfactory. Table II gives the values found during calibration.

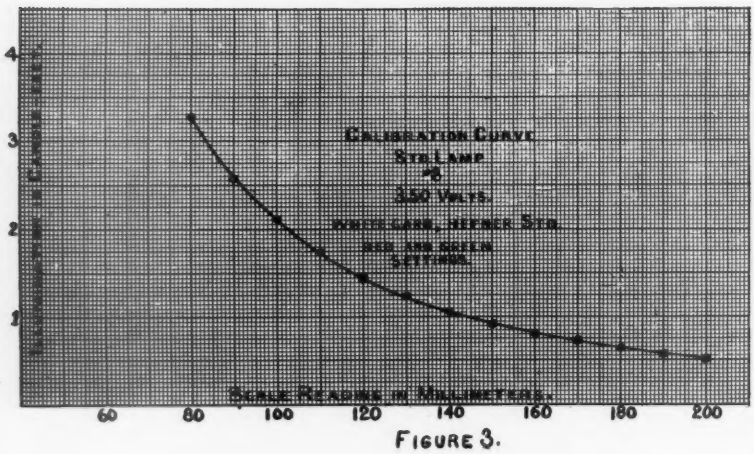


FIGURE 3.

TABLE II.

Scale reading in mms.	Illumination on Card.	
	Before test.	After test.
80	3.28	3.25
90	2.58	2.60
100	2.10	2.11
110	1.73	1.70
120	1.45	1.43
130	1.25	1.28
140	1.07	1.04
150	.930	.900
160	.822	.817
170	.731	.735
180	.654	.649
190	.580	.577
200	.523	.520

When in use the photometer was mounted on a tripod and fitted with a swinging arm, so that the white card could always be brought into the same position with reference to the photometer. Settings could be made with rapidity and ease, in every case a series of settings being made and the mean recorded. The principal difficulty found was in getting the card and Photometer into the proper relative positions without shading the card from the light of some one of the nearer lamps, but in the great majority of cases this was accomplished finally. At Stations 19, 23, 27, 28, and 31, however, there was a certain small shading effect which was found unavoidable.

Table III gives a summary of the results. The first column gives the number of the station, the second the calculated illumination, the third the same quantity as measured, and the last the percentage difference between them.

TABLE III.

No. of station.	Illumination as Calculated.	Illumination as Measured.	Per cent. difference.	No. of station.	Illumination as Calculated.	Illumination as Measured.	Per cent. difference.
1	0.79	0.75	5 0	43	1.30	1.32	1 5
2	1.03	0.98	5.0	44	1.20	1 24	3 2
3	1.08	1.10	1 8	45	1.17	1.20	2.5
4	1 26	1 27	0 8	46	1.15	1.12	2.7
5	1.10	1.00	10.0	47	1.22	1.26	3 2
6	0.98	1.00	2.0	48	1.31	1.38	5.1
7	1.12	1 00	12.0	49	1.58	1.49	6.0
8	1.14	1.14	0.0	50	1.50	1.56	3.8
9	1.26	1.24	1.6	51	1.61	1.69	5.0
10	1.23	1.18	2.8	52	1.51	1.56	3.2
11	1.08	1.04	3.8	53	1.54	1.50	2.7
12	1.17	1.10	6.4	54	1.40	1.44	2 8
13	1.29	1.32	2 3	55	1.32	1.39	5.0
14	1.21	1.19	1.7	56	1 20	1.26	3 2
15	1.12	1.16	3.5	57	1.10	1.12	1 8
16	1.36	1.24	9.7	58	0.80	0.90	11 1
17	1.45	1.47	1.4	59	0.79	0.95	16.8
18	1.46	1.52	4 0	60	0 97	1.20	19 2
19	1.09	1.00	9.0	61	0 88	1.18	25.4
20	1.16	1 20	3.3	62	0 85	1.16	25.9
21	1.12	1.17	4.3	63	0.84	1.17	27.2
22	1.00	1.05	4.8	64	0.89	1.17	23.9
23	1.03	0.97	6.2	65	0 85	0.99	14.1
24	1.23	1.19	3 4	66	0 97	1 10	11.8
25	1.32	1 29	2.3	67	0 93	1.05	11.4
26	1.26	1.20	5.0	68	0.98	1.09	10.1
27	1.15	1.06	8.5	69	1 04	1.11	6 3
28	1.06	0.98	8.1	70	0 82	0.90	8.9
29	1.06	1 05	0.9	71	0.90	0.96	6.3
30	1.13	1.11	1.8	72	0.70	0.75	6.6
31	1.13	1.09	8.3	73	0.70	0 80	12.5
32	1.16	1 07	8.4	74	1.00	1.00	0.0
33	1.20	1.25	4.0	75	1.10	1.20	8.3
34	1.26	1.35	6.7				
35	1.28	1 36	5.9	76	0 80	0 86	7.0
36	1.27	1 21	5.0	77	0.82	0 87	5.8
37	1.14	1 20	5.0	78	0 86	0.77	11.7
38	1.03	1 08	4.6	79	0.72	0 81	11.1
39	1.00	0.95	5.3	80	0.91	0 80	13.8
40	1.20	1.25	4.0	81	0.95	0.97	2.1
41	1.34	1.31	2.3	82	1.13	1.10	2.7
42	1.36	1 30	4.6	83	1.10	1.09	0.9

E. Discussion of Results.

In this table the mean value of the percentage difference between measured and calculated values is 6.6 per cent., the maximum being 27.2 per cent. and the minimum 0.0 per cent. There are, however, only seventeen stations where the difference exceeds 10 per cent., and many of these can be readily accounted for. Thus, Stations 58 to 68, inclusive, are those where the greatest difference exists, and these are the very ones which are most affected by the five small hidden lamps behind the arch, back of the pulpit, the effect of which was not taken into account in the calculation; as their exact location depended upon the detail of the plaster and *papier-maché* work, which was not at hand till long after the calculations were made. These lamps seriously affect points 60, 61, 62, 63 and 64, and I, of course, relied upon them to bring up the illumination where it belonged; but I doubt if they would have had a large effect upon the remainder of the group, and doubtless some others, had it not been for the large amount of *gold leaf* used behind the pulpit, which was an after thought, not put on until almost the last moment before dedication, and the reflection of which I know to be large, but which naturally was not allowed for. I have not thought it wise to recalculate these points, as it is interesting to see what sort of an effect will arise from such changes.

Again, Stations 76 to 83 are in the vestibule, where the tint on the walls is *buff*. In this case no allowance for reflection was made, as the tint was a late decision. I imagine that 78, 79, and 80 are more affected, because they are at those points where the diffuse reflection is proportionately greater. Stations 81, 82, and 83 are fairly close under the dish in the centre of the ceiling, and 76 and 77, to the ball in the alcove. If we omit Stations 58 to 68, inclusive, the percentage difference falls from 6.6 per cent. to 4.8 per cent., and the maximum difference will be 13.8 (this being one of the vestibule stations).

There are, as calculated, twelve stations where the illumination falls under our lower limit, because of shading by columns, etc. (this omits Stations 60, 61, 62, 63 and 64, for the reason noted above, and all stations beyond 75, because the same limits were not there imposed as in the auditorium), and four which rise above the upper limit.

The measurements give similarly twelve falling under and three rising above.

The mean value as calculated, again omitting the same points, is 1.16 candle-feet; by the measurements it is 1.17.

As calculated, the highest value is 1.61, the lowest 0.70; while by the measurements the highest one is 1.69; the lowest, 0.75.

In view of this, I think it fair to say that where the value of the reflection coefficient is fairly well known, and where this type of shade is used, one can, with careful work, come within about 6 per cent. of his calculations.

Plate III shows a number of stations marked in the vestry and parlor. The vestry has, as Plate I shows, an arched ceiling. It is finished with green walls, float-scoured, and with red-oak wainscot, doors, and trimmings.

I would like to have lighted this by concealed lamps behind the cornice (which just shows on Plate I), but it was not deemed best. It is lighted by a 150 C. P. lamp in a 14-inch Holophane ball, hung in the centre of the ceiling, and four two-branch side brackets on the walls, as shown, fitted with 32 C. P. lamps and No. 3105 globes. No calculations were made for this room (except candle-power per cubic foot, which was made to have a value of .022). The measurements at the marked points give a mean value of 2.1 candle-feet, ranging between a maximum under the ball of 2.29, to a minimum of 1.88 on the diagonal midway between ball and corner of the room.

Calculation of a number of points seems to show a value of diffuse reflection from the walls of about 35 to 40 per cent.

Similarly in the parlor, which is finished with terra cotta walls — white, flat ceiling and white trimmings — the folding doors being paneled with tapestry, the mean illumination on the floor at the marked points is 2.25 candle-feet (produced by two ceiling clusters of four 16 candle-power lamps each, fitted with pendant $6\frac{1}{2}$-inch Holophane, Class B, balls), and a calculation of the illumination at a number of points suggests a value of diffuse reflection of about 45 per cent.

In neither of these rooms was it thought worth while to design the illumination with the care used in the case of the main auditorium, and higher values were allowed because the varied uses of the two rooms made a stronger illumination at times desirable.

In another case a hall was to be lighted, the location of the lights being fixed by the wiring, which was already in place; but it was desired to improve the illumination, which was rather poor; due to the facts — first, that the lamps, which originally were simply frosted bulbs, did not distribute in the proper manner; and second, that the candle-power per cubic foot was low. The hall is approximately 48′ × 60′ × 24′ high; it is used for public meetings, dances, lectures, theatrical and other entertainments, etc. The lamps were arranged in a line around the sides of the hall, on the ceiling close to the walls, and in the centre of the ceiling was placed a circle of twelve lights, the lamps hanging about 3 feet down. Under these conditions the effect was something as follows — there was a marked bright spot in the centre, and the illumination fell off gradually toward the walls, in no place being over .85 candle-foot, and the average being about .65 candle-foot. The change made was to replace the side lights by clear bulbs; to make the central ring double the diameter of the original (or 18′), and to put clear glass, 50 candle-power lamps there. This done, the side lamps were then fitted alternately with Holophane stalactites, No. 3150 (throwing the maximum light off at 45°) and No. 3350 (throwing it directly downward), while the central ring was fitted with dishes of similarly alternate action. The result was that the illumination was raised to a mean value of 2.00 candle-feet, the maximum found (out of seventy-five equi-distant points) being 2.12, and the minimum being 1.92.

It is just as easy to calculate what the result will be in simple cases, using opal globes, ground glass balls, etc., as with Holophanes, because the distribution curves are similar in different azimuths; but it is not so simple to calculate and produce a given scheme, because one does not have the same effective method of producing various distribution curves in the same character of globe, and of combining these according to necessities of the case. Similarly, one can by many types of reflectors produce distribution curves as desired, but diffusion is either absent or imperfect; and in many cases the distribution curves differ in different shades and in different azimuths in the same shade, so that each shade strictly ought to be adjusted to exactly the desired position and then always returned to the same. With the Holophanes all this difficulty is avoided.

Of course, the Holophane is not always the most advisable thing to use, any more than is a given type of anything else always the

best ; but I think that it is likely to prove the most generally useful, as well as the most efficient and certain of the aids toward producing a satisfactory illumination of an interior which we possess at the present time.

AN APPARATUS FOR THE RAPID COMPARISON OF VOLTMETERS.

By F. A. LAWS and W. D. COOLIDGE.

In connection with the work of instruction in Electrical Engineering at the Massachusetts Institute of Technology, between seventy and eighty portable voltmeters and ammeters are employed. These instruments are of the best types, and the class of work demanded of the students requires that their errors be known. Consequently it has been necessary to develop a ready means of calibration. We shall here describe our apparatus for comparing direct current voltmeters with a standard instrument. This is done with the hope that the plan of the arrangement used will be of service to others who must keep track of large numbers of measuring instruments.

The apparatus to be described places at the immediate disposal of the operator any voltage between zero and three thousand. This very considerable range demands that proper safety devices be employed to protect the observer from accident and the instruments from injury. The former is rendered the more imperative by the fact that the apparatus is used by students as well as by instructors, and is of necessity situated in a crowded laboratory.

In the diagram (Figure 1) D_1 and D_2 are two similar dynamos, built by the Holtzer Cabot Co. The frames are those of stock machines; the fields are separately excited from a 110-volt circuit; the armatures are specially wound, so that at 1,600 revolutions per minute each machine has an E. M. F. of 1,500 volts, the current capacity being $\frac{1}{4}$ ampere. In order that there shall be little fluctuation of the voltage, the commutators have a large number of segments, 150.

The dynamos are connected to an intermediate shaft, which is supported by independent, self-oiling bearings, and carries a balance wheel, *W*, weighing 100 lbs.; flexible couplings, c_1 and c_2, are provided.

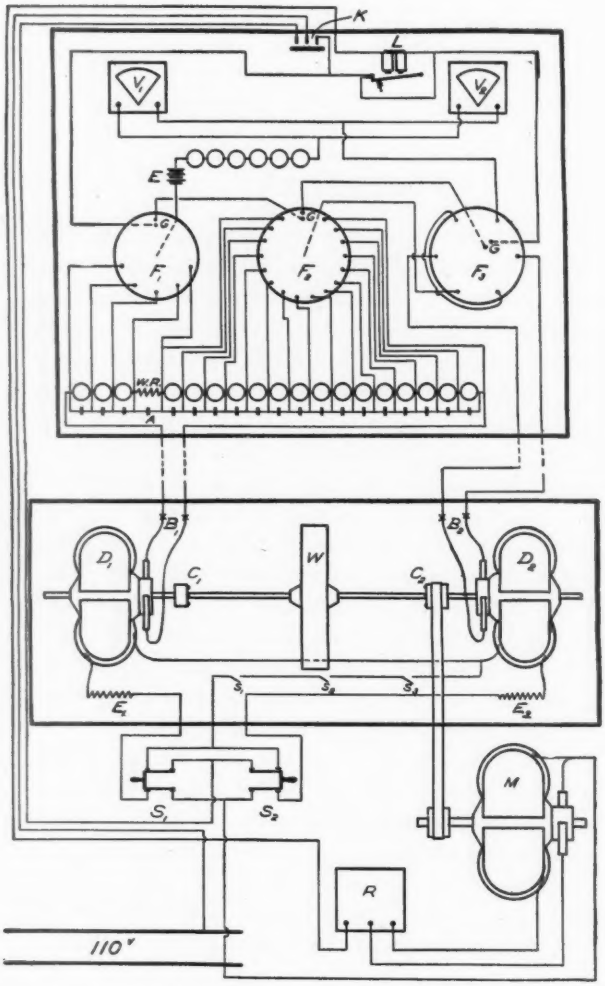


FIG. 1.—DIAGRAM OF THE ELECTRICAL CONNECTIONS IN THE APPARATUS.

To minimize the vibration, the dynamos and intermediate shaft are bolted to a solid framework, very carefully lined up, and supported on pads of hair felt. Power for driving the machines is furnished by a 110-volt direct current motor, provided with an underload-overload starting rheostat, R.

The dynamos are placed in a protective case. This is provided with windows at the side, and the top is formed of three doors. Those at the ends are glazed, and permit the examination of the machines. The middle door carries the switches, S_1 and S_2, the field rheostats, E_1 and E_2, and the starting rheostat, R. Each door is provided with a lock, but in order to render accident impossible, a safety device is added. On the inside of each door is screwed a brass bar, which when the door is closed completes the circuit between two contact springs. The three breaks, s_1, s_2 and s_3, are in series with the common return from the dynamo fields; consequently, opening the case removes the voltage from the machines. Over-load on the machines is prevented by magnetic circuit breakers, B_1, B_2. From B_1 and B_2 the high potential leads run to the calibrating case containing the switches, F_1, F_2, F_3. Those from Machine 1 are connected to a high resistance drop wire, consisting of an adjustable water rheostat, *W. R.*, and 18 incandescent lamps in series. The first three lamps (counting from the left) are 110-volt, 32 c. p.; the other fifteen 220-volt, 16 c. p. The water rheostat has a maximum resistance somewhat greater than that of a 110-volt, 32 c. p. lamp. With 1,500 volts applied to the potential wire, the drop in each 220-volt lamp is approximately 100 volts, in each of the 110-volt lamps, 30 volts, and in the water rheostat, from 0 to 30 volts, according to its adjustment. By means of the 5-point switch, F_1, and the water rheostat, it is possible to tap off from the drop wire any voltage from 0 to 120 volts, and by means of the 16-point switch, F_2, to add to this in steps of 100 volts until the total is 1,500 volts. Then the switch F_3 may be used to put the second machine directly in series with the voltmeter, thus giving 3,000 volts. If F_3 is not used, the machine D_2 runs on open circuit.

The standard voltmeter and the unknown are placed in parallel in the derived circuit. In series with them are placed six 16 c. p. lamps and a small storage battery of three cells. The battery is so inserted that its E. M. F. opposes that of polarization in the water rheostat; consequently the voltmeter readings can be brought exactly to zero. This is of importance when low range instruments are calibrated.

The insertion of the lamp resistance removes the possibility of leaving the storage cells on a low resistance circuit, even if a low range voltmeter is left connected. Also by the use of this resistance the fineness of adjustment when calibrating low range instruments is much increased; for instance, with a Weston 5-volt voltmeter the distance through which the water rheostat must be moved to attain a given adjustment is about nine times as great as it would otherwise be; the lamps also render it impossible to short circuit the dynamos; when working with high range instruments their resistance is by comparison negligible. The water rheostat was given the particular form shown in Figure 2, in order that there might be no loose high potential wire in the case. The movable electrode is supported by a non-conducting cord, which runs over a vulcanite drum operated from outside the case. To prevent evaporation and to guard against the possibility of the removal of the electrode from the liquid, a wooden cover is firmly fastened to the jars. It will be noticed that the removal of the electrode from the liquid or the breaking of a lamp filament might throw a high voltage upon the voltmeter. To guard against injury to the instrument from this cause the water rheostat and each lamp has in parallel with it a small lighting arrester, (*A*), such as is in common use in telephone work. The thickness of the mica is adjusted so that the arc forms at about 300 volts. The efficiency of this device was tested by breaking circuit successively at the various lamps, and it was found that in all cases the arc was established so quickly that there was no symptom of a violent deflection of the needle.

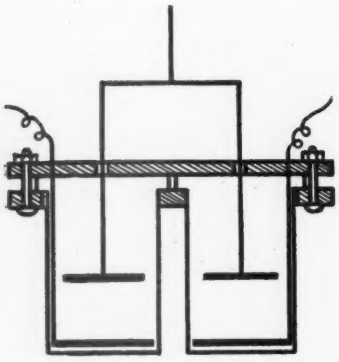


FIG. 2. — SECTION OF THE WATER RHEOSTAT.

The top of the instrument case is closed by a hinged cover which is glazed. Through it project the three vulcanite handles for operating the switches F_1, F_2, F_3. A contact piece, K, screwed to the cover completes the field circuit of the dynamos and motor when the cover is down, but if a person raises the cover, the voltage is thrown off the machines, so that any manipulation is unattended by danger.

The under-load break on the starting rheostat prevents the accidental closing of the motor circuit with no starting resistance inserted, as might be the case if the cover were lowered.

In order to protect the instruments another device was added which renders it impossible to start the motor unless all three switches, F_1, F_2, F_3, stand at zero. This renders it necessary for the operator to always begin at zero and build up the voltage, thereby greatly decreasing the risk of throwing a high voltage on a low voltage instrument through neglecting to note the position of the switches. With this device there is really no excuse for using an improper voltage, for the switches are provided with indices, which show roughly the number of volts applied to the instrument. Re-

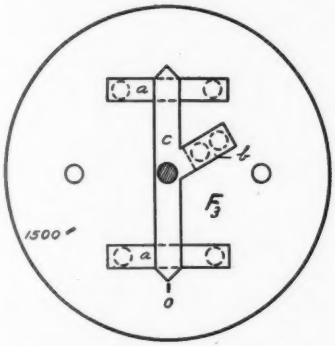


FIG. 3. — SWITCH F_3 IN THE CALIBRATING CASE.

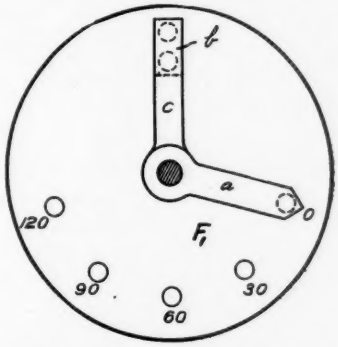


FIG. 4. — SWITCH F_1 IN THE CALIBRATING CASE.

ferring to Figure 1, it will be seen that each of the switches, F_1, F_2, F_3, has a gap G. These gaps are connected in series and brought into the motor circuit. On each of the switches is a second arm, so placed that when the index stands at zero the gap is closed. After the motor is started, a magnetic device, L, closes the main circuit around the breaks and allows the switches to be moved from the zero position. Switches F_1 and F_3 are shown in Figures 3 and 4, where a and b are of spring brass and c of hard rubber.

The dynamo fields are always worked near saturation; this is necessary, for they are supplied from an ordinary lighting circuit. We find as a result of the use of the heavy fly wheel and high excitation that a Weston Voltmeter is readable to $\frac{1}{10}$ volt with ease.

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SOME THERMAL PROPERTIES OF NAPHTHAS AND KEROSENES.

By A. H. GILL and H. R. HEALEY.

In recent years there has been a marked increase in the use of the lighter petroleum oils for fuel purposes, especially for motor vehicles. The data regarding the relative merits of the various naphthas and kerosenes as to their heating value being very meagre, the primary object of this work was to determine these constants. It was also thought desirable to determine some of the other constants, as specific heat and vapor density, but more for scientific interest than for any practical value. Distillations and specific gravity tests were made to characterize the oils, and the flash and fire points of the kerosenes were taken.

For the tests, the so-called 76° Bé. and 62° Bé. naphthas and 135° and 150° fire test kerosenes were used. They were all ordinary commercial oils such as can be readily obtained on the market, and are those usually employed for heating purposes.

The following table gives the specific gravities and the flash and fire points of the kerosenes:

	Degrees Bé.	Specific Gravity.	Flash Point.	Fire Point.
76° Naphtha	76.5°	0.678	.....	.....
62° Naphtha	61.0°	0.733	.....	.....
135° Kerosene.....	48.0°	0.786	125° F.	135° F.
150° Kerosene.....	48.0°	0.788	134° F.	150° F.

Specific Heats. — The specific heats were determined using the apparatus devised by Regnault. This has an inclined cylinder surrounded by a water bath. In this cylinder is a gauze basket in which is placed the substance to be heated, and when at a constant temperature it is quickly lowered into the calorimeter. In ordinary

cases it is the unknown substance which is heated and the calorimeter is filled with water. In this case the procedure was just reversed. The oil to be tested was placed in the calorimeter, and a substance of which the specific heat was known was put in the cylinder. Brass rod about one quarter of an inch in diameter was the material employed, and ten determinations were made of its specific heat. These varied from 0.09198 to 0.09239; the average was 0.09220. This being known, S', the specific heat of the oil is easily obtained from the formula

$$(WS + ws)\ (t_1 - t_2) = (W'S' + w's')\ (t_2 - t_0).$$

The naphthas were troublesome on account of the ease with which they evaporated, thus introducing an error into the weight of the oil. To correct this, tests were made to determine the rate of evaporation at the temperature at which the experiments were carried on. As between three and four hundred grams of oil were used, it is believed that with this correction the error was made practically negligible. Another slight error — not compensated for — is the latent heat of evaporation.

A more important correction was for radiation. On account of the slow conductivity of heat by oil, the ordinary quick method of plotting a curve of temperatures and times and drawing a straight line through the highest point parallel to that part of the curve which represents the rate of cooling, could not be used. A method based upon Newton's law of cooling was therefore employed, giving the final formula for rise of temperature $t_2 - t_1 - a\ (\theta - T)\ m$, in which t_2 is the final temperature, t_1 the initial temperature, a the rate of change per degree difference between t and θ, θ some constant temperature, T the temperature of the calorimeter, and m the interval in minutes between t_1 and t_2.

It is a well known fact that the specific heats of liquids increase rapidly with temperatures. There was not time enough to examine this variation in detail. The results were as follows:

TABLE SHOWING THE SPECIFIC HEATS OF NAPHTHAS AND KEROSENES.

	10° to 20°.	20° to 30°.
76° Naphtha	0.5375	0.5555
	0.5332	
62° Naphtha		0.5044
		0.5032
		0.5038
135° Kerosene.....	0.4766	0.4997
	0.4749	0.4938
		0.4949
150° Kerosene.....		0.4922
		0.4903

From this it would seem that the specific heats increase as the specific gravity decreases.

The agreement of the specific heats of the kerosenes together with the specific gravities and distillation curves, shows that these kerosenes are practically identical except as to flash and fire points, where the 135° kerosene contains a greater amount of more volatile constituents which hardly affect any of the other thermal constants.

It is also well to note the comparatively large differences between the specific heats in a range of temperatures between 10° and 20° C. and those in a range ten degrees higher, *i. e.*, 20° to 30° C. The difference shows very plainly the necessity of stating the range of temperatures along with the specific heats, else all attempts at comparison are practically worthless.

Vapor Density and Molecular Weight. — The petroleum oils are not definite fixed compounds but a mixture of all sorts of hydrocarbons, mostly of the methane series. For this reason, that a certain oil can have no symbol, it might be justly considered unscientific to make molecular weight determinations upon it. However, there are two practical reasons for making the determinations.

The pressure of a mixture of gases is made up of the partial pressures of the constituent gases, and the volume and temperature are the same for all constituents. Hence, the pressure is the only

thing that can vary for the different gases in the mixture, since $PV = RT$.

Now the pressure of each gas depends upon the amount of the gas present (expressed in molecular weights). Thus each different molecular weight is duly represented by its own pressure and weight of substance present. So, therefore, the result obtained is a sum of the molecular weights of the constituents, each constituent having a representation depending upon the amount and molecular weight. In other words, if we assumed the naphthas to be composed of the methane series only, the molecular weight of the naphtha would be nearly the same as that of its principal constituent, or it might express an average of the constituents. Thus 76° naphtha has a molecular weight of 89, which is nearly the molecular weight of hexane, C_6H_{14} (molecular weight, 86), and hexane is known to be the chief constituent of 76° naphtha. And, likewise, octane (molecular weight, 114) is a principal constituent of the heavier 62° naphtha, the molecular weight of which is 112.

The second and more important reason for making the determination was to determine the vapor density. It is desirable to know something about the weight of naphtha vapor in figuring explosive mixtures. This can only be done by determining the vapor density.

For the determination, Victor Meyer's method was employed. The apparatus was the modification used at the Institute, consisting of a small tube inside the regular vaporization tube, through which the bulb of liquid is dropped. A naphthalene bath was used.

The results are as follows:

	62° Naphtha.	76° Naphtha.
	111.8	
	112 3	89.89
	111.6	89.71
Mean	111.9	89.8

Heats of Combustion.

In the burning of an oil there are a number of physical and chemical changes before the final products of combustion are reached. These changes require heat, and the heat thus used should account for the difference between the actual results and the theoretical heat

of combustion figured from the content of carbon and hydrogen. Following along in the order of changes, we have first the raising of the temperature to a point where the oil will vaporize. This includes the specific heat of the oil. Next comes the heat of vaporization. In the burning of a vapor to carbon dioxide and water, it is broken into its elements, carbon and hydrogen. The heat represented by this change is the same as the heat of formation. It is right here that the greatest part of the difference between figured and practical results occurs. According to the theories of thermo-chemistry, every compound has a certain definite intrinsic energy. Energy of elements is assumed to be zero from lack of knowledge. According to the theory of conservation of energy, there can be nothing lost when one system of substances changes into another system, as for instance when methane and oxygen change into carbon dioxide and water. But the sum of the intrinsic energies of the new system is different from that of the first. Therefore there is a difference of energy that must manifest itself, and in the above mentioned change and in chemical reactions in general, it is manifested as heat. In other words, this difference is the heat of combustion of a substance when it reacts completely with oxygen. The heat of formation of a compound is evidently the above mentioned intrinsic energy. It represents the heat given out when elements with zero energy combine to form the new compound. Thus a gram molecule of amorphous carbon uniting with oxygen gives out 97.0 calories. So the heat of formation of a gram molecule of carbon dioxide is —97.0 calories. Likewise, the heat of formation of water is —68.3 calories.

The heat of formation of methane is found as follows:

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$
$$X = -97. - 2 \times 68.3 + 211.9.$$

Thus X, the heat of formation of methane, is —21.7 calories, and the experimental heat of combustion is 211.9 calories for a gram molecular weight.

It is an experimental fact that in any homologous series of hydrocarbons the heats of combustion increase 1,580 K (centruple calories) for each rise of CH_2 in the composition. So that the heats of combustion of the methane series would be 539 K + n1,580 K for a gram molecular weight when n equals the number of carbon atoms.

Now, figuring out the heat of combustion from the content of carbon and hydrogen would give

$$C_nH_{2n+2} + \frac{(3n+1)}{2} O_2 = nCO_2 + (n+1) H_2O.$$

Then the heat of combustion equals

$$n979K + (n+1) 683K = (1{,}653n + 683) K.$$

The heat of formation is the difference of $(1{,}653n + 683)$ K and $(1{,}580n + 539)$ K, which equals $(144 + 73n)$ K. Thus we see that the heat of formation of the methane series also has a regular variation for each CH_2. This is 73 K.

The next point to consider is the resulting volume of gases after combustion. If the volume is increased there is work done, and for a gram molecule the heat equivalent is $2T$ calories, which follows from the equation $PV = RT$. This amounts to considerable in the combustion of hydrocarbons. For example: $C_nH_{2n+2} + \frac{(3n+1)}{2} O_2 = nCO_2 + (n+1) H_2O$. Hence, volume before combustion equals $\frac{3n+3}{2}$, and the volume after combustion equals $2n + 1$, if the steam does not condense. There is therefore an increase of volume of $\frac{n-1}{2}$. The heat equivalent of this is $\frac{(n-1)}{2} 0.02T$, where T is the absolute temperature. This would vary from zero for methane to over twenty for octane, assuming that the gases pass off at 100° C. The remaining part to consider is whether the water formed passes off as a gas or condenses to a liquid. If it condenses, it gives up an amount of heat (97 K per gram molecule, or 0.6 calories per gram) which it would otherwise have carried off.

In the above discussion an attempt has been made to account for the difference between the actual results and those got by the ordinary methods of figuring by an application of the theories of thermochemistry. There are oftentimes confusing divergences in tables on the heats of combustion. But after the above considerations, it often appears that the results are the same when reduced to the same conditions.

In the experiments on the heats of combustion of the oils, a Junkers' gas calorimeter was used. The oil was burned from a plumber's lamp ("Primus" No. 4). In this lamp an air pressure was produced on the surface of the oil by an attached pump. The oil was thus forced out through a small orifice and through a hot tube, where it was supposed to be vaporized before it reached the flame. There was a tube surrounding the heated tube, through which air was admitted. Thus it gave a vigorous blue flame.

To get the weight of the oil burned, the lamp and contents were weighed before and after the run. The runs were usually twenty minutes, and about thirty grams of oil was burned on an average. From theoretical considerations the variations in the heats of combustion should be very slight, and in fact they were.

The following is a summary of the mean results of the various tests:

SPECIFIC HEATS.

Brass 0.09220

	10° to 20°.	20° to 30°.
76° Naphtha	0.5354	0.5555
62° Naphtha	....	0.5045
135° Kerosene	0.4758	0.4961
150° Kerosene	....	0.4912

VAPOR DENSITIES.

76° Naphtha	44.9
62° Naphtha	56.0

HEATS OF COMBUSTION.

	Cal. per gram.	B. T. U. per lb.
76° Naphtha	10.04	18,080
62° Naphtha	9.92	17,860
135° Kerosene	9.89	17,810
150° Kerosene	10.10	18,290

A SHORT METHOD OF FINDING TIME BY EQUAL ALTITUDES OF TWO STARS.

By G. L. HOSMER.

THE following article is a brief description of a special case of the method of finding time by equal altitudes of a heavenly body. The method given here applies to observations made with such instruments as the engineer's transit or the sextant, but should not be used with instruments of greater precision.

If two equal altitudes of a star be taken, one east and one west of the meridian, and the times noted by a watch, then the mean of the observed times is the watch reading when the star crossed the meridian. If the observations are made on the sun, the above relation is not exactly true, but the mean of the observed times must be corrected for the effect of the sun's change in declination, in order to obtain the time of the sun's meridian passage, or apparent noon. The equation for computing the correction is

$$e = -\frac{t\,\Delta}{15}\left(\frac{\tan\varphi}{\sin t} - \frac{\tan\delta}{\tan t}\right) \qquad (1)$$

$$\text{or, } e = A\,\Delta\tan\varphi + B\,\Delta\tan\delta, \qquad (2)$$

where e = correction to be added.
t = half the elapsed time, in hours.
Δ = hourly change in sun's declination.
δ = sun's declination at noon.
φ = latitude of place.

$$\left.\begin{aligned} A &= -\frac{t}{15\sin t} \\ B &= \frac{t}{15\tan t} \end{aligned}\right\} \text{tabulated quantities.}$$

This method has the advantage that the altitudes themselves are not used, so that errors of the instrument do not enter into the computation. In fact, the observation may be made with a transit which has no vertical arc, provided the horizontal axis can be clamped.

The accuracy is greatest when the observer is on the equator and the declination of the sun or star is zero. Near the pole the method is practically useless.

The disadvantage of the method is that we must wait several hours between the observations. It is proposed to overcome this difficulty by observing on two different stars when they are at the same altitude on opposite sides of the meridian.[1] At the instant when they have equal altitudes, the local sidereal time equals the average right ascension of the two stars, $\frac{a_1 + a_2}{2}$, exactly if they have the same declination, approximately if they have slightly different declinations.

Suppose we select two stars whose right ascensions differ by about six hours and whose declinations are nearly the same. A few minutes before it is time for their average right ascension to come to the meridian, we will observe an altitude of the eastern star and note the time by a watch. We then turn to the western star and wait until it has an altitude equal to the first and note the time. We now take the mean of the observed times as being the watch reading corresponding to the sidereal time, $\frac{a_1 + a_2}{2}$. Now, since the declinations of the two stars differ, we may treat the observations as though we had observed on one star only, and it had changed its right ascension and declination uniformly so as to reach the second position at the time of the second observation. In other words, the known relative position of the two stars has bridged over a long interval of time, so that we have accomplished in a few minutes what would otherwise have taken several hours. If we now take $\Delta = \frac{\delta_2 - \delta_1}{a_1 - a_2} =$ hourly change in declination, we may correct $\frac{a_1 + a_2}{2}$ precisely as for a solar observation. It should be noticed

[1] See an article in Van Nostrand's Engineering Magazine, 1878, by L. Wagoner, describing a method of finding latitude, time and azimuth by observations of two stars at equal altitudes.

that since we are now correcting right ascensions, the sign of e is reversed.

In the case of the sun, the hourly change in declination is always less than one minute; consequently, some approximations have been made in deriving the "equation of equal altitudes" (Equation 2), which will not hold good beyond certain limits. It is necessary, before using the equation for this method, to determine how much the two declinations may safely differ. The following numerical test will serve to indicate the magnitude of the error in this formula:

Suppose two stars of declinations $+ 20°$ and $+ 25°$ have each an altitude of $30°$ at a certain instant of time. We will suppose that the latitude of the place is $+ 45°$. We find for the hour angles, $4^h\ 28^m\ 32.8^s$ and $4^h\ 46^m\ 48.9^s$. Then $2t = 9^h\ 15^m\ 21.7^s = a_1 - a_2$, if the observations were made at this instant. The correction should be $9^m\ 08.05^s$. By the formula we get, taking $\Delta = \frac{18{,}000''}{9.256}$, $e = 9^m\ 07.60^s$. The error in the formula is, then, less than half a second for these unfavorable conditions. Therefore, if the declinations differ by $2°$ or $3°$, and are themselves not greater than about $20°$, the formula is sufficiently accurate for observations made with the engineer's transit. It is important that the interval between the observations should be kept very small, otherwise a correction would have to be introduced to allow for the unequal motion of the two stars.

The disadvantages of this method are that (1) we are limited to stars bright enough to be easily identified, and (2) we are somewhat limited in our choice of positions of stars. It is not always easy to find a pair whose mean right ascension is just what we wish and whose declinations differ by a small amount. If one star is bright and the other faint, we may always observe the bright one first, for it makes little difference whether we observe the east star first at a low altitude, and wait for the west star to come down to this altitude, or whether we observe the west star first at a higher altitude and wait for the east star to rise to this altitude. If we observe the bright star first, then we know the altitude at which we must look for the fainter one, and approximately the time at which it will appear in the field. (Its direction may be estimated by the compass needle.)

It is improbable that this method would be the best one in many cases, but it certainly has advantages, for we can in this way find the local sidereal time with little less accuracy than by a transit across

the meridian and without the trouble of laying out a meridian line by observation. The computation is simpler than that of single altitudes, provided we have at hand the tables giving A and B (Equation 2). We also have the advantage of all the accuracy gained by equal altitudes.

We give the following examples to illustrate the method:

EXAMPLE 1.

February 23, 1902.

Latitude, 42° 28′. Longitude, 4*h*. 44*m*. 14*s*. Observed equal altitudes of α Leonis (Regulus) and α Tauri (Aldebaran).

	h.	*m.*	*s.*		*h.*	*m.*	*s.*
Watch,	8	59	00		8	59	00
Stop watch,		1	59.0			1	42.2
Regulus,	8	57	01.0	Aldebaran,	8	57	17.8

Average = 8*h*. 57*m*. 09.4*s*.

	Right Ascension.			Declination.
	h.	*m.*	*s.*	
Regulus,	10	03	11.6	+ 12° 26′ 30″
Aldebaran,	4	30	19.2	+ 16° 18′ 40″
Average,	7	16	45.4	+ 14° 22′ 35″
Difference,	5	32	52.4	3° 52′ 10″

$$\Delta = \frac{13{,}930''}{5.548} = 2{,}511''$$

log Δ 3 3999 *n*	log Δ 3.3999
log *A* 9.4448	log *B* 9 3185
log tan ϕ 9.9615	log tan δ 9.4088
2.8062	2.1272
640.0*s*.	134.0*s*.
134.0	
506.0*s*.	

— 8*m*. 26.0*s*.

	h.	*m.*	*s.*
Average R. A.,	7	16	45.4
e,		8	26.0
Sidereal time,	7	25	11.4
R. A. "Mean Sun,"	22	10	32.7
Reduced to solar time,	9	14	38.7
		1	30.9
Mean local time,	9	13	07.8
		15	46
Eastern standard time,	8	57	21.8
Average watch reading,	8	57	09.4
Watch slow,			12.4

EXAMPLE 2.

February 15, 1902.

Latitude, 42° 28′. Longitude, 4*h*. 44*m*. 14*s*. Observed equal altitudes of β Orionis and α Hydræ.

	Right Ascension.			Declination.	Watch.		
	h.	*m.*	*s.*		*h.*	*m.*	*s.*
α Hydræ,	9	22	48.7	− 8° 14′ 18″	9	19	38
β Orionis,	5	09	51.2	− 8° 19′ 08″	9	20	56
Average,	7	16	20.0	− 8° 16′ 43″	9	20	17.0
Difference,	4	12	57.5	0° 04′ 50″			

$$\Delta = \frac{290''}{4.22} = 68.72''$$

log Δ 1.8371 *n*	log Δ 1.8371 *n*
log *A* 9.4284 *n*	log *B* 9.3579
log tan ϕ 9.9615	log tan δ 9.1627 *n*
1.2270	0.3577
+ 16.9*s*.	2.3*s*.
+ 2.3	
+ 19.2*s*.	

	h.	*m.*	*s.*
Average R. A.,	7	16	20.0
e,			19.2
Sidereal time,	7	16	00.8
R. A. "Mean Sun,"	21	39	00.2
Reduction to solar time,	9	37	00.6
		1	34.5
Mean local time,	9	35	26.1
		15	46
Eastern standard time,	9	19	40.1
Average watch reading,	9	20	17.0
Watch fast,			36.9